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Relationships between Dental Topography, Gross Wear, and Bang and Ramm/Liversidge and Molleson Age Estimates for a Sample of Human Premolar Teeth

Odnosi između dentalne topografije, ukupne istrošenosti cakline, Bang i Ramm/Liversidge te Mollesonov procjena starosti za uzorak ljudskih pretkutnjaka

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Abstract

Objectives: Molar crown wear is often used in bioarchaeological research as a proxy for age at death. However, a small number of researchers have used premolars or compared the application of different methods of relative age estimation. **Material and methods:** Using a sample of 197 previously extracted maxillary first premolars from US dental patients, we considered three protocols for estimating age: the Bang and Ramm/Liversidge and Molleson (BRLM) age estimate method, occlusal topographic analysis, and the Smith system of macrowear scoring. A previous study utilizing the Bang and Ramm method yielded an age estimate range of 9.4 to 10.8 years for the sample. **Results:** Our analyses showed no associations between occlusal topography parameters (occlusal slope, relief, or faceting) and BRLM age estimates, but some concordance was found between Smith scoring and BRLM ages estimates and between Smith scoring and occlusal topography parameters. **Conclusion:** The results of the present study suggest that relationships between gross tooth wear, tooth shape, and dental age estimates are complex, and available methods should be considered together to gain a more comprehensive understanding of how teeth change their shape with wear throughout the lifecourse.

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Introduction

Teeth are used to estimate age at death in a variety of disciplines, including forensics, bioarchaeology, dental ecology, and paleontology (1). The method used for age estimation varies largely by discipline (2, 3, 4, 5).

The gold standard for forensic odontology is the Bang and Ramm method, which uses root translucency as a proxy for age (4). The premise of this approach is that the lumen of dentinal tubules becomes occluded with mineral, thus augmenting light scatter in the root (6). This process begins at the root apex and advances coronally with age (7). This approach has proven to be accurate and precise within the past 5-10 years (8, 9). The Liversidge and Molleson method is of-

Uvod

Zubi se koriste za procjenu dobi u trenutku smrti u raznim disciplinama, uključujući forenziku, bioarheologiju, dentalnu ekologiju i paleontologiju (1). Ovisno o disciplini, metode koje se pritom upotrebljavaju uvelike se razlikuju (2, 3, 4, 5).

Zlatni standard za forenzičku odontologiju jesu Bangova i Rammova metoda koja se koristi translucencijom korijena kao procjenom za dob (4). Pretpostavka pri takvu pristupu jest da lumen dentinskih tubula začepljuju minerali pa se povećava raspršenje svjetlosti u korijenu (6). Taj proces počinje na vrhu korijena i napreduje s godinama prema zubnome vratu (7). Taj se pristup pokazao točnim i preciznim unutar 5

ten used alongside the Bang and Ramm method for teeth that are not fully developed (5, 10). The former involves the length measurement of the crown and developing root. These approaches are limited though, due to variation across populations and the fact that they require access to the root apex – something that is not feasible for *in situ* teeth in bioarchaeological and paleontological samples given the risk of damage to fragile and irreplaceable specimens.

The Smith system, on the other hand, outlines standards for quantifying occlusal macrowear, with potential application to age at death estimation in bioarchaeological contexts (2). This scientific method is a prescribed method for data recording of wear of the anterior dentition and premolars as outlined in the *Standards for Data Collection from Human Skeletal Remains* (11). Smith scores vary by degree and pattern of gross wear as measured by discrete crown attributes, such as presence and extent of faceting and dentin exposure. While patterns can vary independent of age, depending on the focal population and its exposure to dietary abrasives, the strong association between crown macrowear and chronological age within populations of disparate bioregional origin and dietary practices (subsistence, food preparation) (12, 13, 14) suggests that wear variables such as Smith scores can be applied meaningfully for age-at-death estimation. Most aging methods based on crown wear of dentally-mature individuals focus on molars (15). Nevertheless, incisor, canine, and premolar Smith scores can be useful for classifying individuals of unknown age into cohorts for forensic and bioarchaeological application (16).

Occlusal topographic analysis is another method for studying how tooth crowns wear with age (17, 18, 19). This approach focuses on shape changes related to wear. It involves modeling occlusal tables in three dimensions and characterizing topography with measurements of continuous attributes of crown form. Experimental studies have shown that topographic parameters such as average occlusal surface slope, relief (ratio of 3D to 2D surface area), and number of contiguous patches of a given orientation on the surface (OPCr) can all mirror both natural and simulated occlusal wear (20).

Study design and sample selection

The aforementioned methods have their strengths and limitations. Yet we are aware of no direct comparisons between Bang and Ramm/Liversidge and Molleson (BRLM) age estimates, Smith scores, and dental topographic analysis parameters within a single population. In the current study, we compared all of the aforementioned in a sample of unidentified premolars extracted from dental patients in the United States. Extracted premolars were chosen for our study because of their availability in our tooth bank, as well as their potential to supplement molars for wear-based age estimation. In addition to the common tooth extraction reasons in adults, such as periodontal disease, first premolars have traditionally been the tooth of choice for orthodontic extraction in children and adults alike. Therefore, extracted first premolars are widely available across different age groups, unlike other types of teeth, thus making these teeth especially appropriate for this study.

do 10 godina (8, 9). Metoda Liversidgea i Mollesona često se koristi, uz metodu Banga i Ramma, za zube koji nisu potpuno razvijeni (5, 10). Prva uključuje mjerenje dužine krošnje i korijena u razvoju. Ti su pristupi ipak ograničeni zbog varijacija među populacijama i činjenice da zahtijevaju pristup vrhu korijena – nešto što nije izvedivo za zube *in situ* u bioarheološkim i paleontološkim uzorcima s obzirom na rizik od oštećenja krhkih i nezamjenjivih primjeraka.

Smithov sustav, s druge strane, ocrtava standarde za kvantificiranje okluzalnog makrotrošenja s potencijalnom primjenom na procjenu dobi u trenutku smrti u bioarheološkim kontekstima (2). To je propisana metoda bilježenja podataka za istrošenost prednje denticije i pretkutnjaka, kako je navedeno u Standardima za prikupljanje podataka iz ljudskih skeletnih ostataka (11). Smithovi rezultati variraju prema stupnju i obrascu bruto istrošenosti mjereno diskretnim atributima krunice, kao što su prisutnost i opseg fasetiranja i izloženosti dentina. Dok obrasci mogu varirati neovisno o dobi ovisno o žarišnoj populaciji i njezinoj izloženosti dijetalnim abrazivima, snažna povezanost između makrotrošenja krunice i kronološke dobi unutar populacija različitoga bioregionalnog podrijetla i prehrambenih praksi (preživljavanje, pripremanje hrane) (12, 13, 14) sugerira da se varijable trošenja poput Smithovih rezultata mogu smisleno primijeniti na procjenu dobi u trenutku smrti. Većina metoda koje ispituju starenje zuba na temelju trošenja krunica dentalno zrelih osoba usredotočuje se na kutnjake (15). Ipak, rezultati za sjekutiće, očnjake i pretkutnjake, prema stajalištu Smitha, mogu biti korisni za klasificiranje pojedinaca nepoznate dobi u skupine za forenzičku i bioarheološku primjenu (16).

Druga metoda za proučavanje trošenja krunica zuba s godinama jest okluzalna topografska analiza (17, 18, 19). Taj se pristup usredotočuje na promjene oblika tijekom trošenja. Uključuje trodimenzionalno modeliranje okluzalnih tablica i karakteriziranje topografije s mjerenjima kontinuiranih atributa oblika krunice. Eksperimentalne studije pokazale su da topografski parametri, kao što su prosječni nagib okluzalne površine, reljef (omjer 3D i 2D površine) i broj susjednih mrlja određene orijentacije na površini (OPCr), mogu odražavati prirodno i simulirano okluzalno trošenje (20).

Dizajn studije i odabir uzorka

Svaka od nabrojenih metoda ima svoje prednosti i ograničenja, ali svjesni smo da ne postoje izravne usporedbe Bangovih i Ramm/Liversidgeovih i Mollesonovih (BRLM) procjena starosti, Smithovih rezultata i parametara dentalne topografske analize unutar jedne populacije. Ovdje uspoređujemo sva tri u uzorku neidentificiranih pretkutnjaka izvađenih stomatološkim pacijentima u Sjedinjenim Američkim Državama. Ekstrahirani pretkutnjaci odabrani su za istraživanje zbog dostupnosti u našoj banci zuba te zbog njihova potencijala da nadopune molare za procjenu starosti na temelju trošenja. Uz uobičajene razloge za vađenje zuba odraslima, kao što je parodontna bolest, prvi pretkutnjaci tradicionalno su bili zubi izbora za ortodontsko vađenje kod djece i odraslih. Stoga su ekstrahirani prvi pretkutnjaci široko dostupni u različitim dobnim skupinama, što nije uobičajeno za druge vrste zuba, što ih čini posebno prikladnima za ovo istraživanje.

Materials and methods

Dental specimens

Three-dimensional dental scans of 197 right maxillary first premolars (RP^3s in anthropological/paleontological parlance and tooth number 14 according to FDI notation) were used in this study. These specimens were sampled from a collection of unidentified premolars that had been extracted from a random cohort of U.S. dental patients and donated to the Indiana University School of Dentistry's Oral Health Research Institute (Indianapolis, IN). The tooth collection protocol ensured that all extracted teeth were unidentified and not associated with any patient data. The protocol was reviewed and approved by the local Institutional Review Board (IRB #NS0911-07).

Bang and Ramm / Liversidge and Molleson methodology

Dental age estimation methods were originally described in a publication by Algarni and colleagues (21). The Bang and Ramm method was used on fully formed teeth by measuring root dentin translucency (4, 5, 21). The average of the lowest and highest translucency length values from the apex of the root to the enamel-dentin junction (Figure 1) were used to estimate age based on published coefficients (21). For those few specimens without fully developed roots, the Liversidge and Molleson method was used. In these cases, age was estimated using published coefficients (5) for the anterior maxillary premolar associated with the distance between the buccal cusp tip and the edge of the developing root at midline. All measurements were performed using a digital sliding caliper (Fisher Scientific, Waltham, MA, USA) directly on the (unsectioned) extracted teeth, using a standard source of white light – as needed for translucency assessment – by a single trained examiner. Estimated individual ages reported here, ranging from 9.4 to 100.8, were taken from a previously published study of the same clinical sample (21).

Occlusal topography methodology

Teeth with excessive chipping or breakage were excluded from this study as their occlusal surfaces could not be properly analyzed. A 3M True Definition clinical scanner (3M Oral Care, Monrovia, CA, USA) was utilized to scan the premolars. This scanner was designed to generate three dimensional models of teeth in a clinical setting and is readily available for use in many dental practices.

MeshLab and Geomagic Wrap were used to standardize the axes of each scan and to isolate the functional occlusal surface of the premolars (22, 23). Topographic analyses were performed on the cropped occlusal surfaces of each scan using the molaR software package in RStudio (24, 25). The molaR package was used to generate three parameters characterizing crown surface topography: Slope, Relief Index (RFI), and Orientation Patch Count rotated (OPCr).

Slope is defined as the average change in elevation across an occlusal surface (Figure 2). Higher values for Slope are indicative of the presence of higher premolar cusps, which typically corresponds to lower levels of gross wear (17, 20). RFI is a measure of the ratio of a tooth's three-dimensional sur-

Materijal i metode

Stomatološki uzorci

U ovoj studiji korištene su trodimenzionalne dentalne snimke 197 desnih maksilarnih prvih pretkutnjaka (RP3 u antropološko/paleontološkom jeziku i zub broj 14 prema FDI notaciji. Ti su uzorci uzorkovani iz zbirke neidentificiranih pretkutnjaka, a izvađeni su iz nasumične skupine stomatoloških pacijenata u SAD-u i donirani Institutu za istraživanje oralnoga zdravlja Sveučilišta Indiana (Indianapolis, IN). Protokol prikupljanja zuba osigurava da su svi izvađeni zubi neidentificirani i da nisu povezani s podatcima o pacijentu. Pregledao ga je i odobrio lokalni institucionalni odbor za reviziju (IRB #NS0911-07).

Bangova i Ramm/Liversidgeova i Mollesonova metodologija

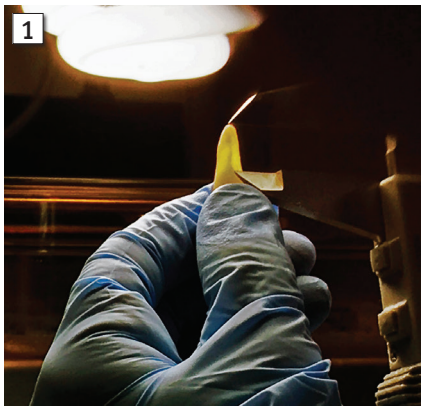
Metode procjene dentalne dobi izvorno su opisane u članku Algarnija i suradnika (21). Metoda Banga i Ramma korištena je na potpuno oblikovanim zubima mjerenjem translucencije korijenskog dentina (4, 5, 21). Prosjek najniže i najviše vrijednosti duljine translucencije od vrha korijena do spoja cakline i dentina (slika 1.) korišten je za procjenu starosti zuba na temelju objavljenih koeficijenata (21). Za tih nekoliko primjeraka bez potpuno razvijenog korijena korištene su Liversidgeova i Mollesonova metoda. U tim je slučajevima dob procijenjena s pomoću objavljenih koeficijenata (5) za prednji maksilarni pretkutnjak povezan s udaljenosti između vrha bukalne kvržice i ruba korijena u razvoju na središnjoj liniji. Sva je mjerenja obavio jedan educirani ispitivač digitalnom kliznom mjerkom (Fisher Scientific, Waltham, MA, SAD) izravno na (nerazrezanim) izvađenim zubima, a koristio se standardnim izvorom bijeloga svjetla – prema potrebi za procjenu translucencije. Procijenjene pojedinačne dobi navedene u ovom tekstu, u rasponu od 9,4 do 10,8, preuzete su iz već objavljene studije istoga kliničkog uzorka (21).

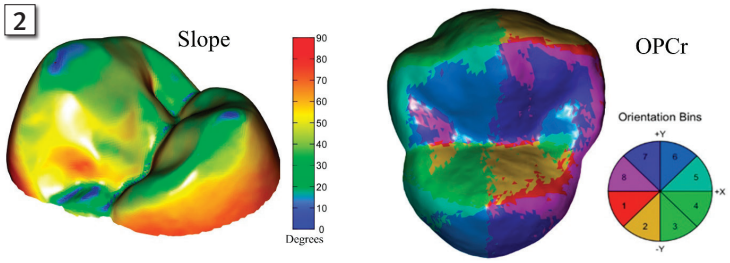
Metodologija okluzalne topografije

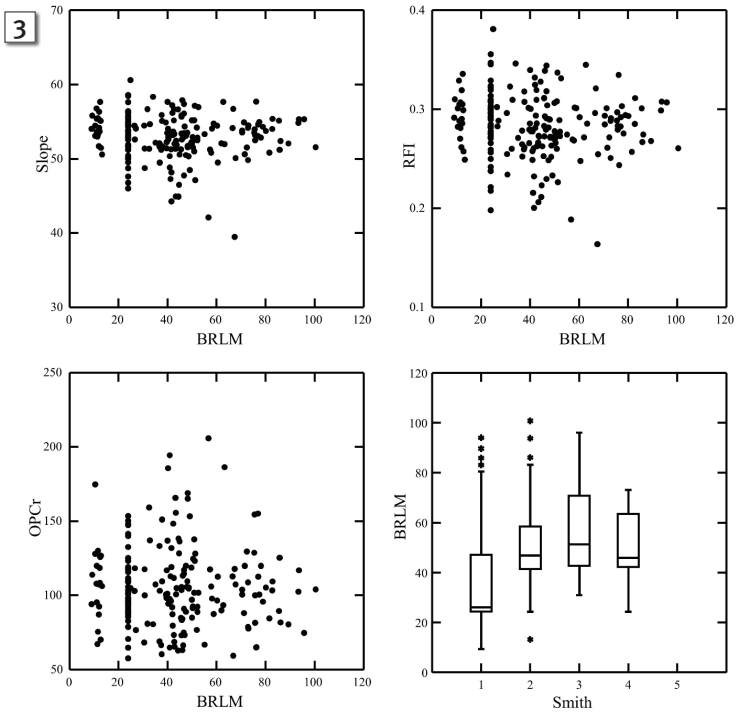
Pretjerano okrhnuti i slomljeni zubi bili su isključeni iz ove studije jer se njihove okluzalne površine nisu mogle pravilno analizirati. Klinički skener 3M True Definition (3M Oral Care, Monrovia, CA, SAD) korišten je za skeniranje pretkutnjaka. Taj uređaj služi za generiranje trodimenzionalnih modela zuba u kliničkom okruženju i dostupan je u mnogim stomatološkim ordinacijama.

MeshLab i Geomagic Wrap korišteni su za standardizaciju osi svakoga skeniranja i izolaciju funkcionalne okluzalne površine pretkutnjaka (22, 23). Topografske analize provedene su na izrezanim okluzalnim površinama svake snimke s pomoću softverskog paketa molaR u RStudio (24, 25). Paket molaR korišten je za generiranje triju parametara koji karakteriziraju topografiju površine krune – to su nagib, indeks reljefa (RFI) i orijentacija Patch Count rotated (OPCr).

Nagib se definira kao prosječna promjena elevacije preko okluzalne površine (slika 2.). Više vrijednosti za nagib indikativne su za prisutnost viših kvržica pretkutnjaka, što obično odgovara nižim razinama ukupnoga trošenja (17, 20). RFI je mjera omjera trodimenzionalne površine zuba i njegova dvo-







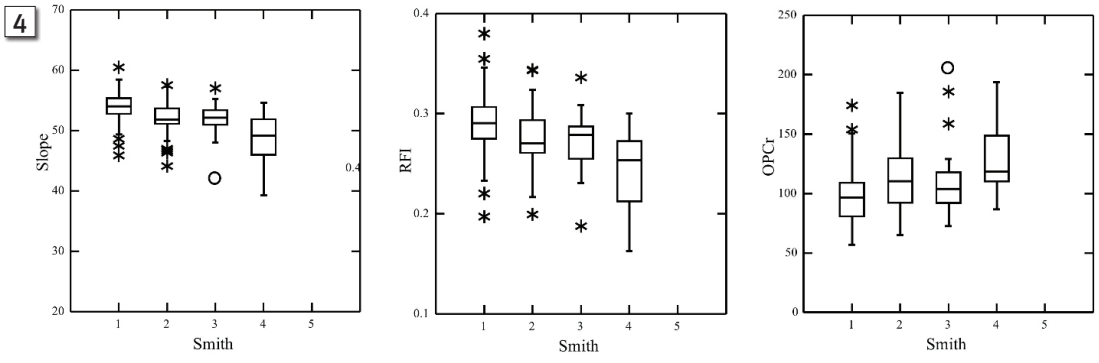


Figure 1 The Bang and Ramm method of age estimation involves measurement of translucency length values from the apex of the root to the enamel-dentin junction.

Slika 1. Bangova i Rammova metoda procjene starosti zuba uključuje mjerenje vrijednosti duljine translucencije od vrha korijena do caklinsko-dentinskoga spoja

Figure 2 Dental topographic analysis of human upper third premolars. Left: molaR-generated images for Slope values as indicated, right: molaR-generated OPCr example.

Slika 2. Dentalna topografska analiza gornjih trećih pretkutnjaka kod ljudi; lijevo slike generirane s pomoću molaR-a za vrijednosti nagiba kako je naznačeno; desno: primjer OPCr-a generiranog s pomoću molaR-a.

Figure 3 Comparisons of Bang and Ramm/Liversidge and Molleson (BRLM) age estimates with dental topography attributes and Smith wear scores for the clinic sample. Bivariate plots of dental topography attributes against BRLM values on top and lower left. Box-and-whiskers plot of BRLM values for different Smith scores on the bottom right. The hinges mark the first and third quantiles, the vertical lines between them are medians, each whisker represents a value 1.5 times the interquartile range, and the asterisks indicate outliers.

Slika 3. Usporedbe Bangovih i Ramm/Liversidgeovih i Mollesonovih (BRLM) procjena starosti s atributima dentalne topografije i Smithovim rezultatima trošenja za klinički uzorak; bivarijantni dijagrami atributa dentalne topografije u odnosu prema BRLM vrijednostima gore i dolje lijevo i dijagram kutije i brkova BRLM vrijednosti za različite Smithove rezultate dolje desno; šarke označavaju prvi i treći kvantil, okomite linije između njih su medijani, svaki brk predstavlja vrijednost 1,5 puta interkvartilni raspon, a zvjezdice označavaju odstupanja

Figure 4 Box-and-whiskers plots comparing topographic attribute values for each Smith score. The hinges mark the first and third quantiles, the vertical lines between them are medians, each whisker represents a value 1.5 times the interquartile range, and the asterisks and circles indicate outliers and far outliers, respectively.

Slika 4. Dijagrami koji uspoređuju vrijednosti topografskih atributa za svaki Smithov rezultat; šarke označavaju prvi i treći kvantil, okomite crte između njih su medijani, svaki brk predstavlja vrijednost 1,5 puta interkvartilni raspon, a zvjezdice i kružići označavaju odstupanja.

face area to its two-dimensional planimetric view. OPCr represents the average orientation patch count of a surface measured at various orientations and indicates the complexity of a tooth's occlusal surface based on the number of faces sorted into eight ordinal directions (19) (Figure 2). RFI typically decreases as teeth flatten with higher levels of wear and their surface areas decrease. On the other hand, OPCr has been shown to be relatively insensitive to variation in gross wear based on comparisons of different primate species (26), although this attribute tends to increase with simulated wear as occlusal surfaces become more multi-faceted (20).

Smith score methodology

Macrowear was scored from the premolar scans using the Smith system (2). The Smith system was originally designed for use in bioarchaeological samples. It utilizes an ordinal scale from 1 to 8, ranging from low ("unworn to polished or small facets") to high ("complete loss of crown, no enamel remaining") levels of occlusal wear, respectively. Each macrowear score is distinguished by standardized, wear-based morphological characteristics, such as facet development, enamel loss, and dentin exposure. Smith scores for this sample were restricted in range from 1 to 4 since the most worn specimens had exposed patches of dentin. However, occlusal enamel was still present.

Statistical analyses

All statistical analyses were conducted using the Systat 12 (27). Data sets were compared two-by-two. First, BRLM age estimates were compared with each topographic attribute (slope, RFI, OPCr) using Spearman's non-parametric correlation coefficients. Smith scores were compared with BRLM age estimates and topographic data using general linear models. An ANOVA model was used with Smith score as the independent variable, while BRLM age estimate was used as the dependent variable. Age estimates were rank transformed to mitigate violation of assumptions inherent in parametric statistics (28). Tukey's HSD and Fisher's LSD pairwise comparisons tests were used to balance risks of Type I and Type II error while determining sources of significant variation (29). A MANOVA model was used to assess the effects of Smith score on rank-transformed topographic data. This allowed comparisons of all individuals in each group. Separate ANOVAs were performed for Slope, RFI, and OPCr, and Tukey's HSD and Fisher's LSD tests were again used to assess sources of significant variation.

Results

Summary statistics are given in Table 1, and results are presented in Figures 3-4 and Tables 2-4. Raw data are available in the supplemental file. Spearman's correlation coefficient values were not significant for comparisons between BRLM age estimates and slope (r_s = 0.122, df = 197, p = 0.088), RFI (r_s = 0.092, df = 197, p = 0.199), or OPCr (r_s = 0.042, df = 197, p = 0.558) (Table 2). In other words, premolar crown shape, as reflected in dental topographic attri-

dimenzionalnog planimetrijskog prikaza. OPCr je prosječan broj orijentacijskih mrlja na površini izmjeren na različitim orijentacijama i upućuje na složenost okluzalne površine zuba na temelju broja lica razvrstanih u osam ordinalnih smjerova (19) (slika 2.). RFI se obično smanjuje kako se zubi splašnjavaju s višim razinama trošenja i njihova se površina smanjuje. S druge strane, pokazalo se da je OPCr razmjerno neosjetljiv na varijacije u ukupnom trošenju na temelju usporedbi različitih vrsta primata (26), iako taj atribut ima tendenciju povećanja sa simuliranim trošenjem kako okluzalne površine postaju višestrane (20).

Smithova metodologija bodovanja

Makroistrošenost je ocjenjivana snimkama pretkutnjaka s pomoću Smithova sustava (2). Taj je sustav izvorno dizajniran za korištenje u bioarheološkim uzorcima. Koristi se redna ljestvica od 1 do 8, u rasponu od niskih („neistrošenih do poliranih ili malih faseta") do visokih („potpuni gubitak krunice, nema preostale cakline") razina okluzalnog trošenja, respektivno. Svaki rezultat makroistrošenosti razlikuje se prema standardiziranim morfološkim karakteristikama temeljenim na trošenju, kao što su razvoj faseta, gubitak cakline i izloženost dentina. Smithovi rezultati za taj uzorak bili su ograničeni u rasponu od 1 do 4, zato što su najčešće istrošeni uzorci imali izložene dijelove dentina, ali je okluzalna caklina još uvijek bila prisutna.

Statističke analize

Sve statističke analize provedene su korištenjem Systata 12 (27). Skupovi podataka uspoređeni su dva po dva. Najprije su procjene starosti BRLM-a uspoređene sa svakim topografskim atributom (nagib, RFI, OPCr) korištenjem Spearmanovih neparametarskih koeficijenata korelacije. Smithovi rezultati uspoređeni su s procjenama starosti BRLM-a i topografskim podatcima korištenjem općih linearnih modela. Korišten je model ANOVA-e sa Smithovim rezultatom kao nezavisnom varijablom i BRLM procjenom starosti kao zavisnom varijablom. Procjene dobi transformirane su u rang kako bi se ublažilo kršenje pretpostavki svojstvenih parametarskoj statistici (28). Tukeyjev HSD i Fisherov LSD, parni usporedni testovi, korišteni su za balansiranje rizika od pogreške tipa I i tipa II dok su se utvrđivali izvori značajnih varijacija (29). MANOVA model korišten je za procjenu učinaka Smithove ocjene na topografske podatke transformirane u rang. To je omogućilo usporedbu svih pojedinaca u svakoj skupini. Provedene su zasebne ANOVA-e za nagib, RFI i OPCr, a TukeyjevimHSD-om i Fisherovim LSD-om ponovno su procijenjeni izvori značajnih varijacija.

Rezultati

Skupna statistika nalazi se u tablici 1., a rezultati su prikazani na slikama 3. i 4. te u tablicama od 2. do 4. Neobrađeni podatci dostupni su u dodatnoj datoteci. Vrijednosti Spearmanova koeficijenta korelacije nisu bile značajne za usporedbe između procjena starosti BRLM –a i nagiba (rs = 0,122, df = 197, p = 0,088), RFI-a (rs = 0,092, df = 197, p = 0,199) ili OPCr-a (rs = 0,042 , df = 197, p = 0,558) (tablica 2.). Drugim riječima, oblik krune pretkutnjaka, kako se odražava u

Table 1 Summary statistics. Median, mean, and SD values for Bang and Ramm/Liversidge and Molleson (BRLM) age estimates and dental topographic attributes (Slope, RFI, and OPCr) by Smith score.
Tablica 1. Sumarna statistika: medijan, srednja vrijednost i SD vrijednosti za Bangovu i Ramm/Liversidgeovu i Mollesonovu (BRLM) procjenu starosti i dentalne topografske karakteristike (nagib, RFI i OPCr) prema Smithovu rezultatu

Smith Score 1, n = 114				Smith Score 3, n = 23			
	Median	Mean	SD		Median	Mean	SD
BRLM	26.100	36.678	21.135	BRLM	51.300	56.548	17.861
Slope	54.046	53.988	2.384	Slope	52.152	51.883	3.020
RFI	0.291	0.291	0.029	RFI	0.279	0.274	0.030
OPCr	96.685	97.794	22.57	OPCr	103.880	111.994	33.021
Smith Score 2, n = 48				**Smith Score 4, n = 12**			
	Median	Mean	SD		Median	Mean	SD
BRLM	46.850	50.373	18.391	BRLM	46.000	50.708	14.606
Slope	51.833	51.997	2.675	Slope	49.207	48.71	4.317
RFI	0.271	0.274	0.030	RFI	0.253	0.244	0.040
OPCr	110.435	113.974	28.085	OPCr	118.250	127.989	30.095

Table 2 Spearman's correlation coefficients for comparisons of Bang and Ramm/Liversidge and Molleson (BRLM) age estimates with dental topography attributes (Slope, RFI, and OPCr). Sample size, $n = 197$.
Tablica 2. Spearmanovi korelacijski koeficijenti za usporedbe Bangovih i Ramm/Liversidgeovih i Mollesonovih (BRLM) procjena starosti s atributima dentalne topografije (nagib, RFI i OPCr); veličina uzorka, n = 197

	Slope	RFI	OPCr
r_s	0.122	0.092	0.042
p	0.088	0.199	0.558

Table 3 ANOVA with Smith Score as the independent variable and Bang and Ramm/Liversidge and Molleson (BRLM) age estimates as the dependent variable for the clinical sample (top). Pairwise comparisons of results for different Smith scores (bottom). All data rank-transformed prior to analysis.
Tablica 3. ANOVA sa Smithovim rezultatom kao nezavisnom varijablom i procjenama starosti prema Bangu i Ramm/Liversidgeu i Mollesonu (BRLM) kao ovisnom varijablom za klinički uzorak (gore); usporedbe rezultata u paru za različite Smithove rezultate (dolje) – svi podatci rangirani su prije analize

	F	*df*	*p*
ANOVA	**13.150**	**3, 193**	**<0.001**
	2	3	4
1	-41.818**	-57.157**	-43.735**
2		-15.339	-1.917
3			13.422

**$p < 0.05$ for Tukey's HSD and Fisher's LSD tests

Table 4 Test results for general linear model tests comparisons of Smith score categories for topographic attributes (Slope, RFI, and OPCr). MANOVA (Wilks λ) and individual ANOVA values (top) followed by pairwise comparisons of variables showing significant variation. All data rank-transformed prior to analysis.
Tablica 4. Rezultati testa za opći linearni model testira usporedbe Smithovih kategorija rezultata za topografske atribute (nagib, RFI i OPCr); MANOVA (Wilks λ) i pojedinačne ANOVA vrijednosti (vrh) praćene usporedbama parova varijabli koje pokazuju značajnu varijaciju – svi podatci rangirani su prije analize

	F	df	p
Wilks λ	10.081	9, 464	<0.001
Slope	15.830	3, 193	<0.001
RFI	10.299	3, 193	<0.001
OPCr	7.754	3, 193	<0.001
Slope	**2**	**3**	**4**
1	43.184**	42.655**	79.601**
2		-0.529	36.417*
3			36.946*
RFI	**2**	**3**	**4**
1	35.072**	32.571**	70.031**
2		-2.502	34.958*
3			37.460*
OPCr	**2**	**3**	**4**
1	-33.811**	-24.511*	-59.561**
2		9.301	-25.750
3			-35.051

**$p < 0.05$ for Tukey's HSD and Fisher's LSD tests.
*$p \leq 0.05$ for Fisher's LSD but not Tukey's HSD tests.

butes measured in this study, did not vary with BRLM age estimates (Figure 3).

ANOVA test results (Table 3) did, however, show significant variation between wear scores and BRLM age estimates (F = 13.15, df = 3, 193, p < 0.001). Median BRLM values tended to be higher with higher Smith scores (Figure 3). This means that elderly individuals tended to show greater premolar wear. Tukey's HSD test results show that Smith score 1 had significantly younger BRLM age estimates than Smith scores 2-4.

The MANOVAs (Table 4) also indicated significant variation between wear scores and topographic attributes (Wilks λ F = 10.081, df = 9, 464, p < 0.001). ANOVA results indicated that Slope (F =15.83, df = 3, 193, p < 0.001), RFI (F = 10.299, df = 3, 193, F = < 0.001, and OPCr (F = 7.754, df = 3, 193, p < 0.001) all varied significantly by Smith score. There is a tendency for decreasing Slope and RFI and increasing OPCr with increasing wear (Figure 4). In other words, crown surfaces get flatter but more faceted with wear. In nearly all cases, Smith score 1 differed significantly from scores 2-4 based on Tukey's HSD test results, except for OPCr comparison of Smith scores 1 and 3, which differed by Fisher's LSD test only. Smith scores 2 and 3 also differed by Fisher's LSD test from score 4 for slope and RFI.

Discussion

Results presented here indicate that there is no association between BRLM age estimate and dental topography attributes (Slope, RFI, or OPCr). On the other hand, there is rough correspondence between age as estimated by BRLM and level of gross tooth wear measured by Smith score. Less worn teeth tend to evince younger age estimates with the BRLM method, especially when comparing individuals with premolar crowns characterized as Smith score 1 (mean age: 37) with those characterized as Smith scores 2-4 (mean ages: 50-57). Still, age estimates vary considerably within each Smith score sample, and there are no significant differences in BRLM estimates between higher Smith score samples. This suggests a fairly limited application of premolar wear scores to biological profiling in bioarchaeological and, especially, forensic contexts, with the extent of their utility being to define broad age cohorts of "younger adults" (<50 years) and "older adults." We note, however, that these results also reflect the challenges of applying a method originally designed for archaeological samples to modern populations characterized by limited macrowear. We discuss these challenges below.

Furthermore, there is a rough correspondence between individual topographic attributes (Slope, RFI, OPCr) and level of gross tooth wear measured by Smith score. Less worn teeth tend to have steeper occlusal slopes, more relief, and less faceting (lower OPCr values) than more worn specimens. But again, there is a lot of variation in topographic attributes within each Smith score sample, and the significant differences are between the extremes (score 4 and especially score 1) and between them and intermediate Smith scores.

dentalnim topografskim svojstvima izmjerenima u ovoj studiji, nije varirao s procjenama starosti BRLM-a (slika 3.).

Rezultati ANOVA testa (tablica 3.) ipak su pokazali značajnu varijaciju između rezultata trošenja i BRLM procjena starosti (F = 13,15, df = 3, 193, p < 0,001). Srednje vrijednosti BRLM-a bile su više s višim Smithovim rezultatima (slika 3.). To znači da su starijim osobama pretkutnjaci bili istrošeniji. Rezultati Tukeyeva HSD testa pokazuju da je Smithov rezultat 1 imao znatno nižu BRLM procjenu dobi nego Smithov rezultat 2 do 4.

MANOVA (tablica 4.) također upućuje na značajnu varijaciju između rezultata trošenja i topografskih atributa (Wilks λ F = 10,081, df = 9, 464, p < 0,001). Rezultati ANOVA-e pokazali su da su nagib (F =15,83, df = 3, 193, p < 0,001), RFI (F = 10,299, df = 3, 193, F = < 0,001) i OPCr (F = 7,754, df = 3, 193), p < 0,001) značajno varirali prema Smithovu rezultatu. Postoji tendencija smanjenja nagiba i RFI-a te povećanja OPCr-a s povećanjem trošenja (slika 4.). To jest, površine krune postaju ravnije, ali više fasetirane s trošenjem. U gotovo svim slučajevima, Smithov rezultat 1 značajno se razlikovao od rezultata 2 do 4 na temelju rezultata Tukeyjeva HSD testa, osim za OPCr usporedbu Smithovih rezultata 1 i 3 koji su se razlikovali samo prema Fisherovu LSD testu. Smithovi rezultati 2 i 3 također su se razlikovali prema Fisherovu LSD testu od ocjene 4 za nagib i RFI.

Rasprava

Ovdje dobiveni rezultati pokazuju da ne postoji povezanost između procjene starosti BRLM-a i atributa dentalne topografije (nagib, RFI ili OPCr). S druge strane, postoji gruba podudarnost između dobi prema procjeni BRLM-a i razine ukupnog trošenja zuba mjerene Smithovim rezultatom. Manje istrošeni zubi pokazuju procjenu mlađe dobi s BRLM metodom, posebno kada se uspoređuju pojedinci s pretkutnjacima okarakteriziranima kao Smithov rezultat 1 (srednja dob: 37) s onima koji su okarakterizirani kao Smithovi rezultati 2 do 4 (prosječna dob: 50 – 57). Ipak, procjene dobi znatno variraju unutar svakoga Smithova uzorka rezultata i nema značajnih razlika u BRLM procjenama između viših Smithovih uzoraka rezultata. To sugerira prilično ograničenu primjenu rezultata trošenja pretkutnjaka na biološko profiliranje u bioarheološkim i, posebno, forenzičkim kontekstima, pri čemu je opseg njihove korisnosti za definiranje širokih dobnih skupina „mlađih odraslih" (< 50 godina) i „starijih odraslih". Primjećujemo, međutim, da ti rezultati također odražavaju izazove pri primjeni metode koja je izvorno osmišljena za arheološke uzorke na suvremenim populacijama koje karakterizira ograničeno makrotrošenje. O tim izazovima raspravljamo u nastavku.

Nadalje, postoji gruba podudarnost između pojedinačnih topografskih atributa (nagib, RFI, OPCr) i razine bruto trošenja zuba izmjerene Smithovim rezultatom. Manje istrošeni zubi obično imaju strmije okluzalne nagibe, više reljefa i manje fasetiranja (niže vrijednosti OPCr-a) nego jače istrošeni uzorci. Ali opet, postoji mnogo varijacija u topografskim atributima unutar svakog Smithova uzorka rezultata, a značajne su razlike između ekstrema (ocjena 4 i posebno ocjena 1) i između njih i srednjih Smithovih rezultata.

The lack of association between BRLM age estimates and occlusal topography parameters is especially unexpected given that BRLM age estimates and occlusal topography parameters both track gross wear as measured by the Smith system, albeit roughly. To put it simply, occlusal Slope, RFI, and OPCr values cannot be used to predict the chronological age of an individual for our clinical sample, at least as estimated by BRLM procedures. The variation in tooth shape between individuals appears to be too great, at least for this sample, which represents a contemporary and genetically-variable population of U.S. dental patients. On the other hand, the rough correspondence between Smith scores and BRLM estimates is consistent with increasing tooth wear with age, at least when comparing individuals with lowest degree of premolar wear to other individuals. Furthermore, differences between occlusal topography attributes by Smith score suggest that crown shape changes in a fairly consistent manner as wear progresses. Again, this is especially the case for comparisons of individuals with unworn or minimally worn teeth (Smith score 1) to other individuals.

One possible explanation for the lack of association between age estimates and occlusal topography attributes is that genetically mediated variation in occlusal form or variation in diet among individuals adds noise to the system, obscuring any relationship between the two variables for this clinical sample. Analyses of samples consisting of more homogeneous populations (e.g., uniform bioregional affiliation, similar dietary behaviors) than that represented by the Indiana University School of Dentistry's Oral Health Research Institute tooth bank is needed to test these hypotheses. In addition, this sample is restricted in its macrowear profile (i.e., no individuals characterized by Smith scores 5-8), likely due, in part, to the relatively soft, highly processed diet typical for US populations today. The lack of highly worn teeth in this study may have obscured relationships between macrowear, age, and occlusal topography, thus impacting our results.

Our results are also limited because there were no definitive age values for the study. In this way, our findings are more directly transferrable to bioarchaeological contexts, where unknown chronological age is reconstructed from any available skeletal or dental indicator. In contexts where teeth are the only elements preserved, it is useful to understand the complex relationship between progressive changes across distinct hard tissues (i.e., root translucency versus crown wear). Importantly, our results indicate that these relationships are not always one-to-one. While the lack of actual age and other identifying information for this sample allowed the teeth to be anonymized and dissociated from any patient data in accordance with IRB-approved protocols, our results could, ideally, have compared known ages to each of these three age estimation methods. Further studies are needed to evaluate individual age and sex for these purposes.

In addition, further research is needed to consider other tooth types and to devise more specific applications and combinations of these three methods to best serve bioarchaeological, functional morphological and forensic purposes. Clement and Hillson found that a divergence of wear patterns occurred based on cultural practices and a gendered di-

Nedostatak povezanosti između procjena starosti BRLM-a i parametara okluzalne topografije posebno je neočekivan s obzirom na to da procjene starosti BRLM-a i parametri okluzalne topografije prate ukupno trošenje mjereno Smithovim sustavom, iako grubo. Jednostavno rečeno, vrijednosti okluzijskog nagiba, RFI i OPCr ne mogu se koristiti za predviđanje kronološke dobi pojedinca za naš klinički uzorak, barem kako je procijenjeno BRLM postupcima. Čini se da su biološke varijacije u obliku zuba između pojedinaca prevelike, barem za ovaj uzorak, koji predstavlja suvremenu i genetski varijabilnu populaciju stomatoloških pacijenata u SAD-u. S druge strane, gruba podudarnost između Smithovih rezultata i BRLM procjena u skladu je s povećanjem trošenja zuba s godinama, barem kada se uspoređuju pojedinci s najnižim stupnjem trošenja pretkutnjaka s ostalima. Nadalje, razlike između atributa okluzalne topografije prema Smithu sugeriraju da se oblik krunice mijenja na prilično dosljedan način kako trošenje napreduje. Opet, ovo je posebno slučaj za usporedbe pojedinaca s neistrošenim ili minimalno istrošenim zubima (Smithov rezultat 1) s drugima.

Jedno moguće objašnjenje za nedostatak povezanosti između procijenjene dobi i atributa okluzalne topografije jest da genetski posredovana varijacija u okluzalnom obliku ili varijacija u prehrani među pojedincima dodaje *buku* u sustav, prikrivajući bilo kakav odnos između dviju varijabli za ovaj klinički uzorak. Za testiranje tih hipoteza bio bi potreban rad na uzorcima iz homogenijih populacija (npr., ujednačena bioregionalna pripadnost, slično prehrambeno ponašanje) od onih koje predstavlja banka zuba Instituta za oralno zdravlje Sveučilišta Indiana. Nadalje, ovaj je uzorak ograničen u svojem profilu makrooblačenja (tj. nema pojedinaca okarakteriziranih Smithovim rezultatima 5 – 8), vjerojatno, djelomično, zbog razmjerno mekane, visoko prerađene prehrane tipične za današnje stanovništvo SAD-a. Nedostatak jako istrošenih zuba u ovoj studiji mogao je zamagliti odnose između makrotrošenja, dobi i okluzalne topografije, što je utjecalo na naše rezultate.

Naši su rezultati također ograničeni jer nisu postojale konačne vrijednosti dobi za studiju. Na taj način naši se nalazi mogu izravnije prenijeti u bioarheološke kontekste, gdje se nepoznata kronološka starost rekonstruira iz bilo kojega dostupnog skeletnog ili zubnog pokazatelja. U kontekstima u kojima su zubi jedini očuvani elementi, korisno je razumjeti složeni odnos između progresivnih promjena na različitim tvrdim tkivima (tj. translucencije korijena nasuprot trošenju krunice). Važno je da naši rezultati pokazuju da ti odnosi nisu uvijek jedan na jedan. No dok je nedostatak dobi i drugih identifikacijskih podataka za taj uzorak omogućio anonimiziranje zuba i odvajanje od bilo kojih podataka o pacijentu u skladu s protokolima koje je odobrio IRB, naši bi rezultati idealno usporedili poznatu dob sa svakom od ovih triju metoda procjene dobi. Buduće studije trebale bi razmotriti procjenu individualne dobi i spola u te svrhe.

Potrebna su daljnja istraživanja da bi se razmotrile druge vrste zuba i osmislile specifičnije primjene i kombinacije tih triju metoda kako bi najbolje poslužile u bioarheološke, funkcionalne morfološke i forenzičke svrhe. Clement i Hillson otkrili su da su se razlike u obrascima nošenja dogodile

vision of labor within a genetically isolated Inuit community, for example, which indicates a need to better understand the confluence of both biological and social factors that can impact patterns of tooth wear beyond age (30).

Conclusions

Smith scoring, occlusal topographic analyses and BRLM age estimation have roles to play in the study of tooth wear, shape, and age estimation. That said, none of these attributes are an especially good proxy for other attributes, at least for maxillary first premolars, and none of these attributes can replace the other attribute, given the evidence for within-sample variation. Thus, there is value in combining approaches to gain the most complete picture possible of how teeth in different populations change shape with wear and age, especially in bioarchaeological contexts (31, 32).

Conflict of interest

None declared

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na temelju kulturnih praksi i rodne podjele rada unutar genetski izolirane inuitske zajednice, na primjer, što upućuje da je potrebno bolje razumijevanje kad je riječ o stjecanju bioloških i društvenih čimbenika koji mogu utjecati na obrasce trošenja zuba (30).

Zaključci

Smithov scoring, okluzalne topografske analize i BRLM procjena starosti važni su za proučavanje trošenja, oblika i procjene starosti zuba. Ipak, ni jedan od tih atributa nije posebno dobra zamjena za ostale, barem za prve gornje pretkutnjake, i nijedan ne može zamijeniti ostale, s obzirom na dokaze o varijacijama unutar uzorka. Stoga postoji vrijednost u kombiniranju pristupa kako bi se dobila najpotpunija moguća slika o tome kako zubi u različitim populacijama mijenjaju oblik s trošenjem i starenjem, osobito u bioarheološkom kontekstu (31, 32).

Sukob interesa

Autori nisu bili u sukobu interesa.

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Sažetak

Svrha: Trošenje zubne krune kutnjaka često se koristi u bioarheološkim istraživanjima za procjenu dobi u trenutku smrti. No u nekoliko takvih analiza upotrijebljeni su pretkutnjaci ili se uspoređivala primjena različitih metoda procjene relativne dobi. **Materijal i metode:** Koristeći se uzorkom od 197 izvađenih prvih maksilarnih pretkutnjaka stomatoloških pacijenata iz SAD-a, u radu razmatramo tri protokola za procjenu dobi – prema Bangu i Ramm/Liversidgeu te Mollesonu (BRLM), okluzalnu topografsku analizu i Smithovu metodu za sustav bodovanja makroistrošenosti. U prethodnoj studiji koja se koristila metodom Banga i Ramma dobiven je raspon procijenjene dobi od 9,4 do 10,8 godina za uzorak. **Rezultati:** Naše analize nisu pokazale povezanost između parametara okluzalne topografije (okluzalni nagib, reljef ili faseta) i procjene starosti BRLM-a, i određenu podudarnost između Smithova bodovanja i procjena starosti BRLM-a te između Smithova bodovanja i parametara okluzalne topografije. **Zaključak:** Dobiveni rezultati sugeriraju da su odnosi između gruboga trošenja zuba, njihova oblika i procjene starosti složeni, a dostupne metode treba razmotriti zajedno kako bi se stekло sveobuhvatnije razumijevanje o tome kako zubi tijekom života trošenjem mijenjaju oblik.

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