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Antemortem tooth loss as a biomarker of poverty: Dental evidence of "weathering" in a contemporary U.S. skeletal sample

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ABSTRACT

In societies where resources are unequally distributed, structural inequities can be physically *embodied* over lifetimes. Lived experiences including racism, sexism, classism, and poverty can lead to chronic stress that prematurely ages body systems. This study tests the hypothesis that members of structurally vulnerable groups will exhibit premature aging in the form of antemortem tooth loss (AMTL). Analyzing Black, Indigenous, and People of Color (BIPOC) and white skeletal donors from the University of Tennessee, we predict that individuals from structurally vulnerable groups will exhibit more AMTL than individuals with more social privilege. We find some evidence for increased AMTL in BIPOC individuals, but significantly more AMTL in low-socioeconomic-status white individuals than either BIPOC or high-SES white individuals. We maintain that high rates of AMTL provide evidence of embodied consequences of social policies and utilize the violence continuum to theorize the ways in which poverty and inequity are normalized in U.S. society.

1. Introduction

In societies where wealth and opportunity are unequally distributed, experiences of social inequity can become physically harmful to those who live through them, leading to negative impacts on the body's adrenal, cardiovascular, immune, neurological, and reproductive systems [1–5]. The social experiences of living as a member of a systematically marginalized group can include being denied access to education, employment, medical care, health information, and nutritive food choices (among other basic human rights), all of which have the potential to detrimentally impact mental and physical health [6–10].

Through this process, termed *embodiment* [11–13], social experiences may become biologized—literally incorporated within human bodies over lifetimes. For example, socioeconomic status (SES) gradients often track with health gradients, with individual health becoming poorer with each step down the SES hierarchy [3]. Major contributors to poor health include labor precarity [14] and the resulting feelings of unpredictability and inability to control one's life [15], along with the acute, psychosocial stress born from recognizing one's comparative SES, internalizing it, being repeatedly made to feel it, and experiencing the deterioration of one's social capital [3,9]. Likewise, social categories like race, while invalid descriptors of human biological variation, have the potential to feedback into biology, resulting in racialized health disparities. For example, among living U.S. populations, the *weathering hypothesis* [16,17] has shown that the overall health of Black Americans declines cumulatively, beginning in early adulthood, compared to white Americans, due to living with the chronic stress of social inequity. This early deterioration contributes overall to accelerated aging processes and, ultimately, earlier onset of health issues and disabilities [18–20].

While public health workers and medical anthropologists have spent decades examining the biological repercussions of these chronic stressors in living individuals (e.g., summarized in Refs. [7,18,19,21]), the ways in which embodied social processes might impact skeletal and dental tissues are still poorly understood. This is of particular relevance to forensic anthropologists—specialists in human skeletal and dental anatomy who frequently work in contexts of human rights violations, homicide investigations, and/or other casework involving the remains of systematically marginalized decedents [22–24].

Specifically, the theoretical framework termed *the violence continuum* [25] can help to illuminate the forensic anthropological understanding of social processes potentially impacting skeletal biology [26]. The violence continuum showcases the varied forms violence may take while analyzing how each type of violence—structural, everyday, symbolic, and direct political—affects individual physical and mental health.

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Structural violence is indirect; it cannot be traced to a source, as it is produced through unequal power distributions that create violent conditions at individual and population levels, such as inequitable resource access [27,28]. *Everyday violence* is often so normalized that it goes unquestioned, most explicitly manifesting in the form of violent, population-level trends such as high infant mortality rates and rampant disease [29]. *Symbolic violence*, exemplified in abiding class and power relations through generations, is an internalized form whereby individuals misrecognize implicit meanings in ordinary interactions and practices, allowing violence to be exacted on and by the same individuals [25]. *Direct political violence* is exemplified by interactions between brutal militant state regimes and oppositional forces.

Dental anthropologists and bioarchaeologists have long considered the hard-tissue embodiment of lived experiences of violence in archaeological samples. Looking at biomarkers like dental attrition and antemortem tooth loss (AMTL), they have identified local diet, crop yield, subsistence strategies, food processing techniques, dental ablation, nutritional deficiency diseases, and traumatic injuries as sources of socially meaningful patterns in the archaeological record, often intersectionally delineated by gender and/or social status (e.g., Refs. [30,31]; [32]; [33]). Forensic anthropologists have also begun to consider the impacts of structural violence on human skeletal and dental remains. Within the past decade, research has investigated the physical embodiment of chronic stressors in deceased individuals within contexts ranging from Latin American migrants to the U.S. [34,35] to historical experiences of poverty [36,37] and racism [38–41]. However, aspects of the violence continuum other than structural violence tend to be incompletely theorized in forensic anthropological research, and the weathering hypothesis [16,42] has never been explicitly tested on skeletal or dental remains.

This study aims to fill this research gap. In it, we test the hypothesis that members of structurally vulnerable groups will exhibit premature aging in the form of AMTL and utilize the violence continuum to interpret our results. Known to be correlated with age [43], AMTL is sometimes used by forensic and other biological anthropologists as a general indicator of age at death [44]. Yet, in addition to age, AMTL is associated with a constellation of factors that can be structured by social inequity, including poverty, substance abuse, and lack of access to dental care [3,15,45–50]. As such, we propose AMTL as a potential biomarker of structural vulnerability. Examining a modern sample of U.S. Black, Indigenous, and People of Color (BIPOC) and white individuals, we propose that: 1. AMTL will increase with advancing age and concomitant skeletal senescence, as age is positively correlated with increased periodontal disease risk, which is a main driver of AMTL [51–53]; 2. Due to lived experiences of social marginalization, inequity, violence, and its subsequent embodiment at the individual level, BIPOC will exhibit more AMTL than white individuals of both low and high SES; and 3. Due to lived experiences of poverty and its subsequent embodiment at the individual level, lower-SES white individuals will exhibit more AMTL than higher-SES white individuals. We utilize the violence continuum to interpret our results.

The potential for the weathering hypothesis to be visible skeletally has direct relevance to forensic anthropological estimation of the biological profile—specifically, age estimation—as the remains of prematurely weathered individuals may "look older" than their chronological age and thus result in an inaccurate age estimate. Further, if biomarkers of lived social inequity are visible on the body's hard tissues, this poises forensic anthropologists to speak truth to power, articulating in their casework and advocacy the negative impacts of social policies that go beyond merely 'skin deep' [23,26,54,55]. As such, this research has relevance not only to forensic anthropological practice but also to the context of health, disease, inequity, and resource access in the broader U.S. sociocultural context.

By investigating not only age but also the embodied social factors that, we predict, will contribute to AMTL, this study contributes to our understanding of forensic anthropological age estimation as well as to the growing body of scholarship on the biocultural nature of health and aging and the physical effects of living while socially marginalized.

2. Materials and methods

2.1. Study sample

A sample of 183 modern skeletal individuals from the *UTK Donated Skeletal Collection* [56,57] was analyzed. All individuals were born in the 20th century, and most resided in Tennessee. All individuals were kin- or self-donors, and all had associated life history information. However, as the *UTK Collection* curates substantially more white than BIPOC donors [24,56], documentation of SES was more frequently available for the former (100%, versus 58% of the BIPOC subsample). As such, SES was not considered when assembling the BIPOC sample, but it was instrumental in assembling the white sample, which includes low- and high-SES subgroups. This is not to equate potential experiences of structural racism to those of living in poverty; rather, the lack of reported SES data for the BIPOC sample remains a confounding variable in this study, as discussed below (see *Study Limitations and Future Research*).

As the smaller number of BIPOC donors was the limiting factor in sample creation, this subsample (n = 56) was chosen first. The BIPOC subsample is comprised of all kin- or self-donated skeletal individuals available for analysis who identified as "Black" (n = 31), "Biracial," (n = 14), "Hispanic,"(n = 9), or "American Indian" (n = 2), regardless of SES (Table 1). The two white subsamples (low-SES n = 63; high-SES n = 64) were then chosen specifically to mirror the age breakdown of the BIPOC sample (see Table 1). White donors were chosen at random within family reported childhood SES categories: those reported as "upper" or "upper-middle" were included in the high-SES subsample; and those reported as "lower" or "lower middle" were classified as low-SES (see Table 1). However, in order to match the established age distribution, 22 individuals of "middle"-reported SES were included; in these cases, occupational data were used to attribute the individuals to either the low- or high-SES white subsamples (e.g., "blue collar" workers such as janitors and cashiers were considered low-SES; "white collar" workers such as lawyers, doctors, and engineers were considered high-SES).

2.2. Data collection

All 183 skeletal individuals were analyzed for AMTL without knowledge of sample demographics to reduce the likelihood of confirmation bias (e.g., scoring a BIPOC individual as having more AMTL after viewing information on their social race). First, each tooth was scored as either present ("P") or absent ("A"). When tooth crypts were empty but showed no remodeling, and the associated teeth were present for rearticulation, these teeth were scored as "P." Dental implants, crowns, and veneers were scored as "P" as they still provided a functional masticatory surface and would have appeared present socially (sensu [58,59]). In absence of dental records and detailed patient histories for the sample decedents, there was no way to differentiate between a tooth that was intentionally extracted antemortem versus one that was simply lost antemortem; both were scored as "A." This was deemed sufficient for the purpose of a study focusing on equity and access to dental care, as instances of tooth extraction may equally represent emergency dental care situations prompted by infrequent care or evidence of continual, preventative care. Additionally, without detailed dental histories, there was no way to account for potential instances of congenitally absent teeth. Yet, it should be noted that neither approach to tooth loss implemented herein (Eichner Indices and tooth counts) included third molars—the most variable and frequently absent tooth in the human dentition [60]—and that the frequency of congenitally absent, non-M3 permanent teeth is relatively low [61].

Eichner Indices were then assigned based on present occlusal pairs [43,62,63]. The Eichner Index considers the first and second molars, premolars, and anterior teeth as functional, occlusal support zones

Table 1
Sample by ancestry[a], socioeconomic status, sex, and age.

Subsample	Age-At-Death Group								
	<20	20–29	30–39	40–49	50–59	60–69	70–79	>80	TOTAL
Low-SES White Female	0	2	4	6	6	6	6	2	32
Low-SES White Male	1	1	3	6	6	6	6	2	31
High-SES White Female	0	2	3	6	6	7	6	2	32
High-SES White Male	1	2	2	6	6	6	7	2	32
"Biracial" Female	0	0	1	0	1	4	1	1	8
"Biracial" Male	0	0	1	0	3	1	1	0	6
American Indian Female	0	0	0	0	0	1	1	0	2
Black Female	0	0	1	0	3	2	3	1	10
Black Male	0	1	1	4	4	6	5	0	21
Hispanic Female	0	0	1	1	1	0	0	1	4
Hispanic Male	0	1	0	3	1	0	0	0	5
TOTAL	2	9	17	32	37	39	36	11	183

[a] "Ancestry" is the term used in *UTK Collection* documentation to describe a donor's social race. Note that all racial identity terminology in this table also follows *UTK Collection* documentation. Racial identities are relevant to the current study not because they imply hereditary differences between human groups but rather because of the potential for racialized inequities to become embodied.

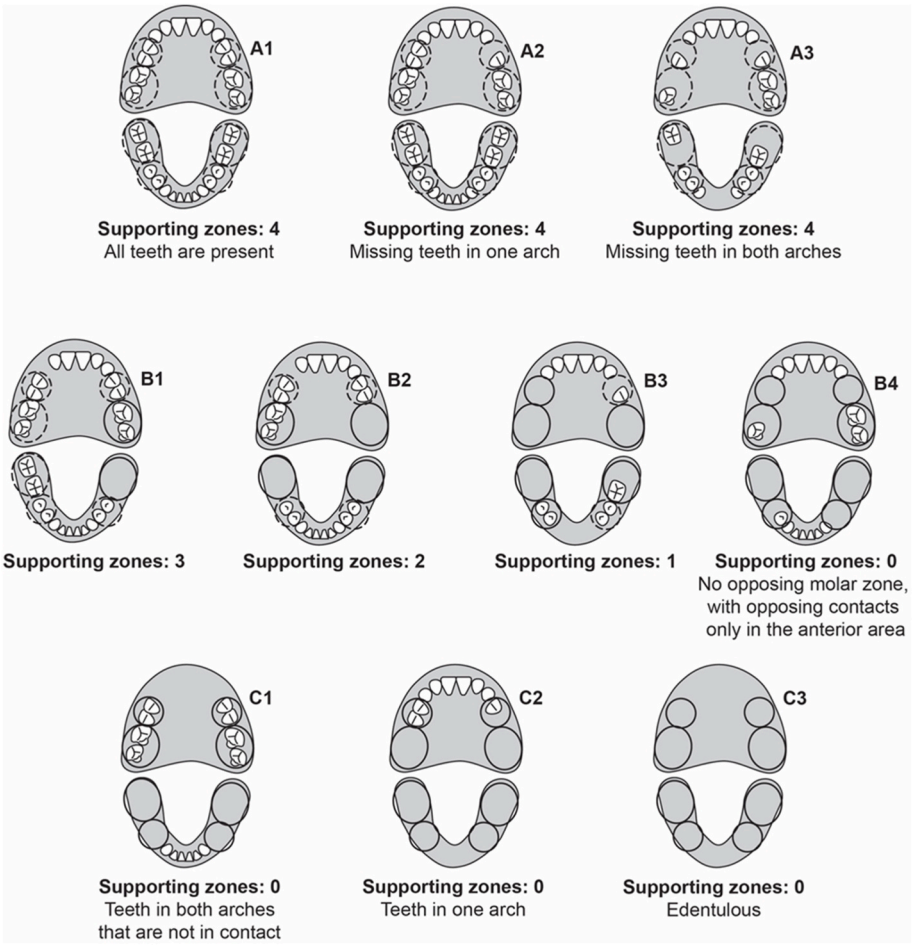

Fig. 1. Eichner Index descriptions. Figure modified by the second author after Fig. 1 in Ref. [62]; in accordance with CC law.

(Fig. 1). For example, an individual with all of their adult teeth would have four occlusal support zones because their maxillary and mandibular molars would meet (two zones), and their maxillary and mandibular premolars would meet (two zones). There are three levels of occlusal pairs: A, B, and C (see Fig. 1). Within level A, there are three variants—A1, A2, A3—that represent different conditions whereby an individual has four occlusal support zones. There are four variants in B, each of which corresponds to a decreasing number of occlusal zones: B1 (three zones), B2 (two zones), B3 (one zone), and B4 (no zones). Finally, there are three variants in C—C1, C2, and C3—each of which describes a different way for an individual to exhibit zero occlusal support zones. The difference between B4 and C1-3 is that B4 still has opposing anterior teeth.

Finally, the total number of present teeth per individual were counted. As discussed above, and consistent with the Eichner Index, third molars were excluded from the counts. Presence was preferenced in the tooth-count analyses because of the inability to identify specific conditions related to teeth lost antemortem in the absence of patient-

specific dental records.

2.3. Data analysis

All statistical tests were run in *R* ([64];v4.2.2; critical α set at $p < 0.05$). Sex differences in Eichner occlusal zone patterning and tooth presence counts were tested within the low-SES and high-SES white subgroups via Kruskal-Wallis tests. Sex differences could not be tested within the BIPOC sample due to small sample sizes and lack of associated SES and occupational data, along with statistically significant age differences between BIPOC females and males (ANOVA; $F = 4.458$, $p = 0.039$).

Shapiro-Wilk tests indicated that age distributions were normally distributed for the BIPOC ($p = 0.912$), low-SES white ($p = 0.632$), and high-SES white subsamples ($p = 0.225$). Accordingly, an ANOVA—a parametric test that analyzes the variance of means between normally distributed data—was run to compare the age distributions between the BIPOC, low-SES white, and high-SES white subgroups. Kaplan-Meier survivorship curves were also generated and compared between the three subsamples using the "survival" package in *R* [65].

Spearman's rank-order correlation (*rho*) was utilized to test for associations between age and number of Eichner occlusal support zones for the full sample and each of the three subsamples, as well as between age and tooth presence counts for the full sample and each subsample. To further interrogate the relationship between age and tooth loss, transition analysis [66,67] was performed on the Eichner occlusal data (the dataset most appropriate for modal grouping/binarization) using binomial generalized linear models (GLMs) with the probit link function and log-scaled age, all performed in the "VGAM" package in *R* [68]. These analyses generated modal ages-of-transition, as well as estimates of the ages at which 90% and 95% of the individuals in each of the subsamples transitioned from having one or more occlusal support zones to having zero occlusal support zones.

Distributions of the number of Eichner occlusal support zones for the three subgroups were analyzed via Kruskal-Wallis tests. A Dunn's test was conducted post hoc with all three subgroups to confirm the direction of significance. Eichner Index scores were then examined for trends among the age-at-death groups and subsamples via log-linear analysis. The distributions of present teeth per individual (excluding third molars) were compared via a Kruskal-Wallis test between each subsample. A Dunn's test was conducted post hoc with all three subgroups to confirm the direction of significance.

3. Results

3.1. Sample demographics

An ANOVA one-way analysis of variance indicated no statistically significant differences in the age distributions for the 56 BIPOC individuals, 63 low-SES white individuals, and 64 high-SES white individuals ($F = 0.321$, $p = 0.725$; Fig. 2). Kaplan-Meier survivorship curves also depict no noticeable differences in subsample age distributions (Fig. 3). Kruskal-Wallis tests revealed no statistically significant differences between the low-SES white males and females ($p = 0.772$) or between the high-SES white males and females ($p = 0.153$) in Eichner occlusal zone patterning. Kruskal-Wallis tests also indicated a similar lack of statistically significant difference between sexes in tooth presence counts: low-SES white males and females ($p = 0.812$); high-SES white males and females ($p = 0.645$). As summarized above, sex differences within the BIPOC sample could not be tested.

3.2. Numbers of occlusal zones and present teeth

Per the Eichner Index, the median numbers of remaining occlusal zones were: low-SES white = 0; BIPOC = 1; and high-SES white = 2.5 (note that the median of 2.5 for the high-SES white subgroup reflects an equal number of individuals who had 2 and 3 occlusal support zones). A score of 0 indicates that the individual may only have opposing contact left at their anterior teeth, but no longer have occlusal support zones between their molars or premolars. A score of 1 indicates the individual has one occlusal support zone either between opposing molars or premolars. A score of 2 indicates the individual has two occlusal support zones either between opposing molars or premolars. A score of 3 indicates the individual has three occlusal support zones either between opposing molars or premolars (see Fig. 1). In a complete dentition, an adult individual has 4 occlusal support zones.

For the tooth-count analyses, the median numbers of present teeth out of 28 were as follows: 13 teeth for the BIPOC subsample, 7 teeth for low-SES white, and 23 teeth for high-SES white (Fig. 4).

3.3. Hypothesis testing

Testing Hypothesis 1, that AMTL would increase with age, Spearman's correlation tests indicated significant ($p < 0.001$) negative correlations between age and number of occlusal zones for the full sample (*rho* = −0.472), BIPOC sample (*rho* = −0.600), low-SES white sample

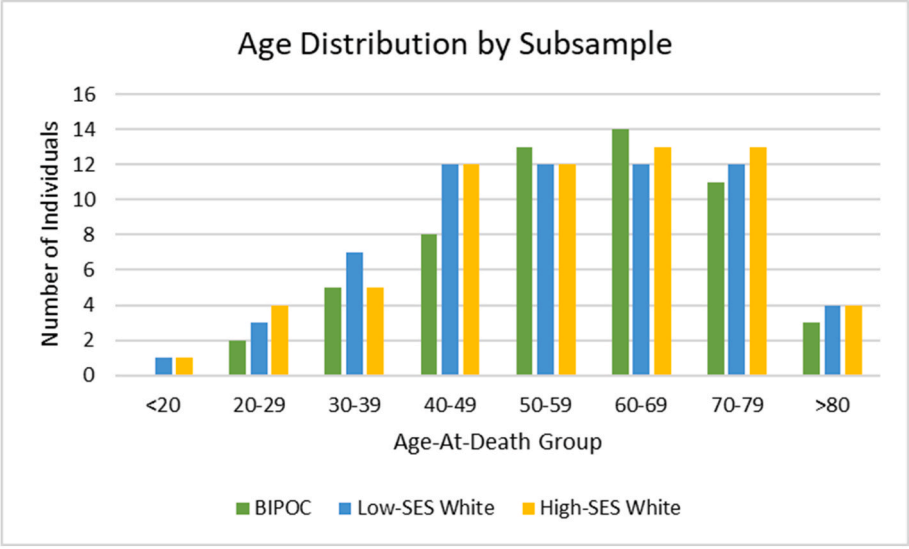

Fig. 2. Sample age-at-death distribution for BIPOC, low-SES white, and high-SES white subsamples.

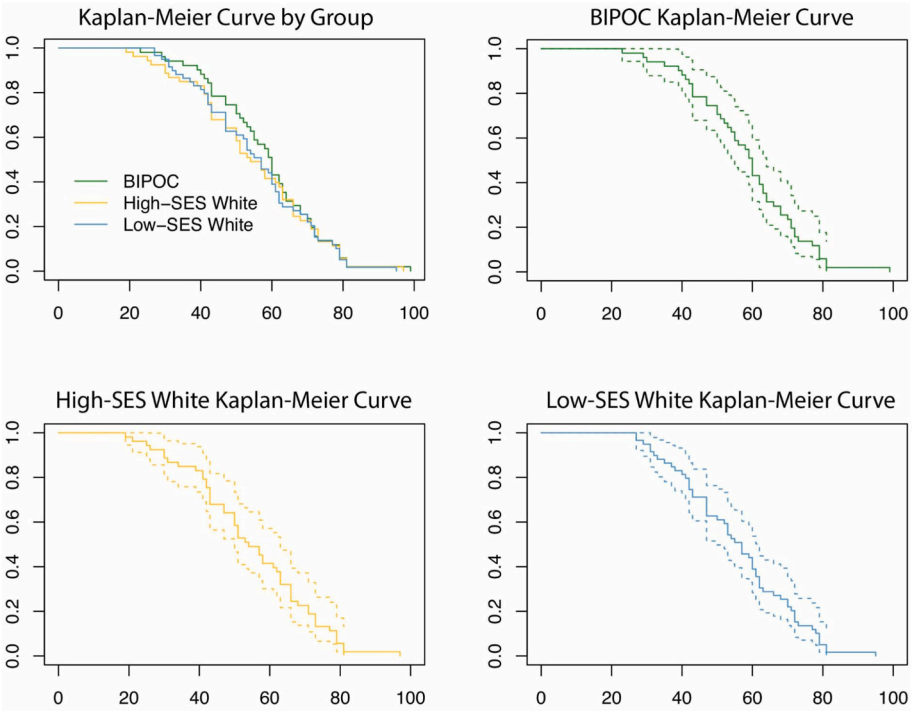

Fig. 3. Kaplan-Meier survivorship curves comparing the groups within the sample: BIPOC, high-SES white, and low-SES white. Individual subsample plots contain dashed lines indicating 95% confidence intervals. For all plots, abscissae are age-at-death in years and ordinates are percentages of the overall sample.

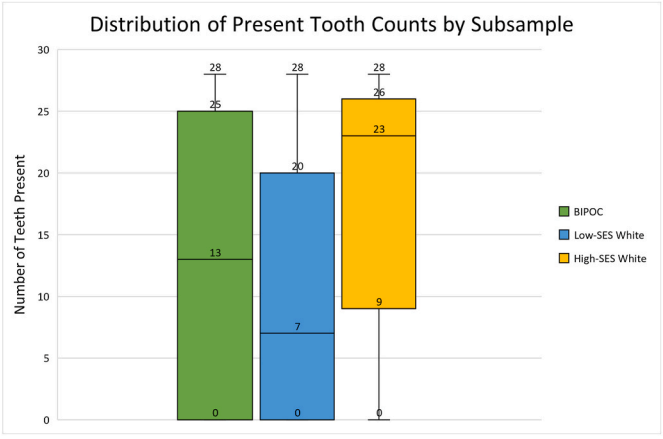

Fig. 4. Distribution of present tooth counts (excluding third molars) for BIPOC, low-SES white, and high-SES white subsamples.

(*rho* = −0.427), and high-SES white sample (*rho* = −0.490). In essence, as age increased, the number of teeth decreased. Based on these significant results, transition analysis was utilized to further explore the relationship between age and tooth loss. However, due to the overlapping age ranges of individuals in each subsample who had one or more versus no occlusal support zones in their dentition, the GLMs did not resolve. In other words, the estimated 90% and 95% ages at transition for AMTL were exceedingly high—often substantially older than the human lifespan (>110 years)—because a significant proportion of the elderly individuals retained at least one support zone, whereas some young-adult individuals did not (Table 2).

For the tooth-count analyses, present teeth decreased with age, supporting Hypothesis 1. Spearman's correlation tests indicated significant ($p < 0.001$) negative correlations between age and number of present teeth for the entire sample (*rho* = −0.471), BIPOC sample (*rho* = −0.525), low-SES white sample (*rho* = −0.476), and high-SES white sample (*rho* = −0.507). The similar *rho* values for the full sample by age and Eichner occlusal zones (*rho* = −0.472) as well as age and present tooth counts (*rho* = −0.471) suggests that the patterning of retained occlusal zones is an accurate representation of overall dental attrition as supported by raw tooth count data.

Table 2
Results of transition analysis using probit-link binomial GLMs and log-scaled age, including modal ages of transition and ages at which 90% and 95% of each sample transitioned from retaining at least one occlusal support zone to having no occlusal support zones present.

Sample	Mode age of transition (yrs)	90% age of transition (yrs)	95% age of transition (yrs)
BIPOC	39.5	98.3	113.8
High-SES White	39.2	168.6	212.6
Low-SES White	25.7	89.9	109.8

In testing Hypotheses 2 and 3, a 3-group Kruskal-Wallis test was performed between each subgroup and the number of occlusal zones present, yielding a significant output ($X^2 = 11.061$; $p = 0.003$; $df = 2$). Hypothesis 2, that BIPOC individuals would have more AMTL than similarly aged white individuals, was rejected following a Dunn's post hoc test ($p = 0.109$). Hypothesis 3, which states that lower-SES white individuals would exhibit more AMTL than the higher-SES white sample, was supported (Dunn's post hoc; $p < 0.01$). Further, not only did low-SES white individuals exhibit more AMTL than the high-SES white sample, but they also exhibited more AMTL than the BIPOC sample (Dunn's post hoc; $p = 0.03$).

The present-tooth-count data was used to test Hypotheses 2 and 3 by loading the presence count data per subgroup into a 3-group Kruskal-Wallis test, yielding significant results ($X^2 = 12.219$; $p = 0.002$; $df = 2$). Hypothesis 2, that BIPOC individuals would have more AMTL than similarly aged white individuals, was only supported between the BIPOC and high-SES white samples by a Dunn's post hoc test ($p = 0.027$). Hypothesis 3, which states that lower-SES white individuals would

exhibit more AMTL than the higher-SES white sample, was also supported (Dunn's post hoc; $p < 0.01$). The distribution of present teeth per subsample is visualized in Fig. 4.

Log-linear analyses were performed to assess the relationships between Eichner indices, age-at-death groups, and sample subgroups, as well as the number of occlusal support zones present (0–4), age-at-death groups, and sample subgroups. Count data was input per each individual's Eichner Index variant, age-at-death group, and sample subgroup designation into a two-way model, yielding no significant outputs. However, inputting count data per each individual's number of occlusal zones present, age-at-death group, and subgroup designation yielded two significant interaction effects (Table 3). The results indicate that the high-SES white donors statistically significantly retained more teeth via more occlusal zones present (see Table 3) than the low-SES white and BIPOC donors.

Although not statistically significant per the log-linear analysis results, the distribution of Eichner indices across the three subsamples showed a distinct pattern (Fig. 5). Aligning with the second log-linear analysis results, the high-SES white group generally retained more teeth in the form of occlusal support zones than the other two subgroups, evidenced by the high counts of A1, A2, and B1 indices (see Fig. 5). Conversely, the low-SES white group generally retained fewer teeth, evidenced by high counts of C2 and C3 Eichner indices. Yet, these Eichner index trends were not statistically significant in the log-linear results likely due to unequal variance partitioning between each index. Accordingly, having four occlusal support zones is split among three Eichner indices and having zero occlusal support zones is split among four Eichner indices, while having 1–3 occlusal support zones are represented by singular indices.

4. Discussion

Forensic anthropologists are commonly tasked with building biological profiles to aid in making personal identifications. Metric and morphological methods currently exist that enable us to successfully estimate aspects of a decedent's biology that may map onto relevant social variables and serve to advance an identification. Yet, traditional methods fail to consider the potential for embodied structural inequity and intersectional violence to impact skeletal individuals, relying too frequently on assumptions of hereditary differences and individual decisions in order to interpret skeletal and dental variation. In line with this special issue's other contributors, we argue that the focus must shift toward the identification of upstream factors that pattern this variation, including structural inequities that may be identified and described in social systems globally, in order to reform and/or produce methods that best serve all case decedents and act against postmortem violence [25,69–71].

In the past decade, forensic anthropologists have made important theoretical and methodological strides toward revealing the embodied impacts of structural violence on skeletal decedents (e.g., Refs. [34,35,72–75]). However, lived inequity likely takes more forms among forensic case decedents than just structural violence, given the recurrent nature of death, murder, homicide, and suicide and the interplay between the components of the violence continuum. Direct political violence may very well be identifiable in forensic casework, particularly in cases of human-rights abuses, where state and other actors come into direct conflict and marginalized groups are often targeted [26]. Symbolic and everyday violence, while more difficult to visualize forensically, may be identified using a combination of contextual and biological factors. For example, a case decedent with extreme dental disease, non-medically set fractures, and extensive osteoarthritis who was found outdoors in association with a large assemblage of personal effects might have experienced everyday violence in a society in which houselessness is normalized and overlooked [23,26,76].

This study served as a first attempt to investigate whether embodied structural inequity and intersectional violence result in the weathering, or premature aging, of the body's hard tissues. Specifically, this research investigated the age correlation of AMTL (via Eichner Indices and present tooth counts) and compared AMTL among three modern skeletal subsamples of U.S. residents. In BIPOC and white skeletal donors from Eastern Tennessee, AMTL did show a statistically significant negative correlation with age in all three subgroups and with both approaches to tooth loss; this indicates that as age increases, the number of teeth generally decreases. Yet, transition analysis of binarized Eichner data failed due to the large degree of overlap in age ranges between individuals with versus without occlusal support zones—a dichotomization that was necessary to perform the binomial GLM given the constraints of the subsample sizes and complexities of Eichner index scoring. However, while the GLMs did not resolve in a manner compatible with using AMTL for age estimation, it is interesting to note that the modal ages-of-transition to zero occlusal support zones were essentially equal in the BIPOC and high-SES white samples (39.5 and 39.2 years, respectively), while the mode age for the low-SES white sample was substantially lower (25.7 years).

As such, AMTL may be more accurately viewed as a biomarker of lived experiences—particularly poverty and potentially other forms of social inequity—than as an age-correlated phenomenon. Specifically, our tooth-count data demonstrate that the high-SES white sample had statistically significantly more teeth present than both the BIPOC and low-SES white samples, supporting the hypothesis that lived experiences of poverty translate to more AMTL. The Eichner Index data also support the hypothesis that low-SES white individuals would have more AMTL than high-SES white individuals. In fact, the sample's low-SES white donors exhibited statistically significantly more AMTL than both their BIPOC and high-SES white counterparts when comparing Eichner occlusal zones. Conversely, the sample's high-SES white donors displayed statistically significantly less AMTL in the form of occlusal support zone retention, potentially revealing life-long effects of preventative dental care access in the form of regular dental cleaning visits that allowed higher-SES individuals to maintain better oral health. While our hypothesis that BIPOC decedents' embodied experiences of living in a racialized society would translate to poorer dental health (and thus, more AMTL) was unsupported by the Eichner data, this hypothesis was partially supported by the tooth-presence-count data. Thus, our results suggest that lived experiences of low-SES—encompassing poverty, precarity, social inequity, deterioration of social capital, and the repetitive feelings of such—"weather" structurally vulnerable skeletal decedents in ways that are observable and measurable to forensic anthropologists.

In an attempt to understand the mechanism for these differences in AMTL—particularly striking in low-SES white decedents—we considered the study sample in the context of the Opioid Epidemic. Opioid overprescription is known to disproportionately impact individuals who experience poverty or other forms of social marginalization [77]. Specifically, overprescription of opioids to white residents of Eastern Tennessee is well documented: in 2018, Knox County had the highest rate of opioid prescriptions filled in the East Tennessee region, followed by the neighboring Blount County [78]. According to the state of Tennessee's 2020 Annual Overdose Report, white Tennessee residents have consistently had higher rates of opioid overdose deaths than their Black counterparts from 2014 to 2018 [79]. People with opioid dependencies

Table 3
Log-linear analysis significant outputs for counts per subsample, age group, and number of occlusal zones present.

Coefficients	Estimate	Standard Error	z-value	*p*-value
High-SES White and 3 Occlusal Zones Present	1.546	0.741	2.087	0.037
High-SES White and 4 Occlusal Zones Present	1.503	0.548	2.743	0.006

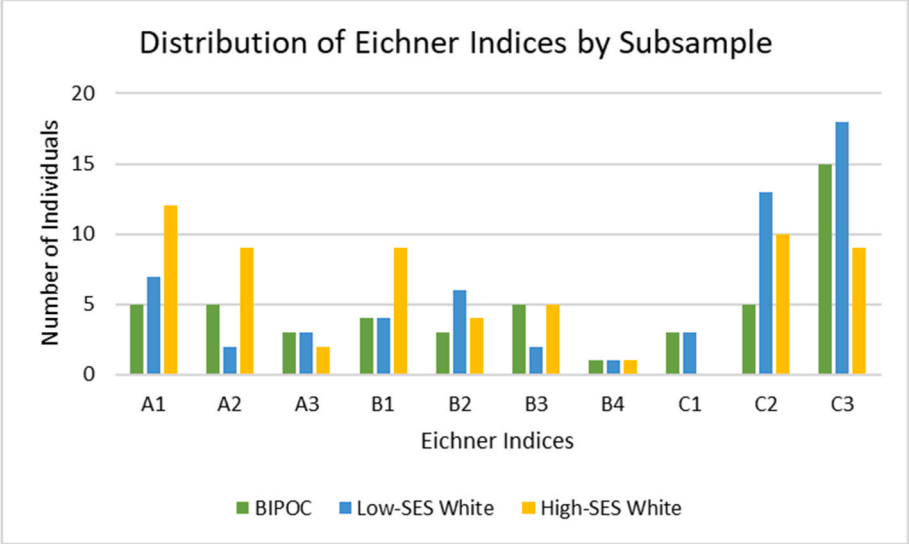

Fig. 5. Eichner Index distribution for BIPOC, low-SES white, and high-SES white subsamples.

typically suffer from increased rates of dental caries and oral diseases due to a complex suite of factors including behavioral changes, physiological changes in taste (i.e., toward sucrose; [50]), and the body-numbing effects of excess opioid consumption, which can conceal oral pain until it reaches an extreme level [45]. Yet, there is no self-reported use of opioids documented in the sample, although many donors reported other substance use, like alcohol and cigarettes. Further, even if there were, Tennessee's Annual Overdose Report (2020) shows that drug use and overdose are strongly correlated with *higher*-SES areas in the East Tennessee region (e.g., Knox, Sevier, Blount, and Anderson counties). Thus, opioid use fails as an explanation for the social forces keeping low-SES groups in poorer dental health.

Poor oral health in the low-SES white sample may be better explained as an aspect of generalized poor health produced by structural inequity and symbolic violence. Structural inequity suspends individuals' and communities' access to high-quality resources—such as healthcare, food, education, jobs, and housing—and often dissolves social support networks, leaving individuals feeling fragmented and hopeless [3,15]. Further, the choice to go (or not go) to the dentist may well be shaped by one's own feeling of shame for their poor dental hygiene, or fear of being ridiculed by others. These feelings may be reinforced and perpetuated by cycles of symbolic violence in which poverty is internalized and poor dental health is justified. The suspension of resources that may result in poor dental hygiene may thus exist as a symbolically violent marker of poverty. Reviews of the medical literature indicate that low-SES individuals have poorer quality of life related to oral health than middle-SES and high-SES individuals, irrespective of country, age group, or SES indicator [46]. In Tennessee, specifically, dental care access is limited, with approximately 27% of the state's population living in a Dental Health Professional Shortage Area (DHPSA) in 2016 [80]. Low-SES white individuals in East Tennessee may thus be disadvantaged to a point where oral healthcare is outside their accessible healthcare services [47–49]. Contrarily, however, a 1993 study of 300 patient dental records from Memphis, TN indicated that Black patients were experiencing faster rates of AMTL than their white counterparts, with patterns of AMTL similar to records from the 1960s, a time since which their white counterparts had displayed overall oral health improvements [81]. This example is not directly analogous to dental care experiences in the Eastern Tennessee region as Memphis is a larger metropolitan area with a major dental school, but it serves to broaden the temporal scope of AMTL trends among Tennessee residents. While, as we explore above, opioid use is inadequate to explain the extreme AMTL in this low-SES white sample, it should be noted that disproportionate reliance on substances is also socially structured, as people who cannot access healthcare resources to mediate pain or alleviate mental and physical illness may self medicate with illicit substances. This recurrent cycle in which their social invisibility forces low-SES individuals to sustain harmful long-term consequences in their pursuit of short-term relief is itself a form of everyday violence.

Social policies often play a direct role in determining dental care access. Since 2000, public insurance in the U.S. has grown with access remaining most restricted for low-income, BIPOC, and senior individuals [82,83]. Even if individuals have access to dental care, significant cost barriers remain without prophylactic care coverage. Unlike medical insurance which covers preventive services, dental insured patients may still pay out-of-pocket for over 40% of all costs [82]. In the U.S., the omission of adult dental coverage from Medicaid in California correlated with a significant and immediate increase in emergency department visits for dental problems by Medicaid-enrolled adults [84]. Notably, Tennessee has opted out of the country's relatively recent Medicaid eligibility expansions [80]. Yet, even in states where these Medicaid expansions have occurred, resulting in millions of low-income adults gaining healthcare and dental benefits, this has not led to equitable access to dental care for low-income adults, as these changes have not come along with requisite capacity building for dental care providers [85]. Further policy-level developments may need to pivot toward expanding the dental care system generally to accommodate more individuals.

Recent scholarship has documented lived experience implications related to AMTL, both functionally and aesthetically. According to Ref. [43], AMTL is the main driver of gross mandibular morphological change rather than aging itself. Morphological alterations to the human mandible can produce increased strain in mechanical loading and change in the overall masticatory environment, making chewing more difficult and reducing an individual's bite force [86–88]. Aesthetically, teeth bear significant social meaning, too. For example, having a full, white smile versus a smile missing teeth stands as a symbolically violent class signifier in the U.S.—demarcating the haves and have-nots [83]. This lived reality may discourage individuals with non-conforming dentition from smiling, especially if their "social six" anterior teeth appear unconventional [58,59]. Additionally, individuals with non-conforming dentition may internalize it in ways that confirm their larger SES rank, resulting in chronic psychosocial stress with adverse health consequences [3,9]. Thus, living with AMTL may produce deleterious corollaries, including impaired masticatory function and personal health decline.

4.1. Study limitations and future research

This study's focus on embodied inequity may serve to obscure the effects of resilience in mitigating negative aspects of these individuals' lived experiences [89,90]. Resilience can be defined within social sciences as a general persistence, and at times resistance, to adverse and/or violent circumstances [91,92]. Thus, the individuals in this study may have been effectively combating chronic stress and violence through life, potentially mitigating more marked manifestations of weathering that could otherwise have been observable postmortem.

It should also be noted that most of this study's donors were residents of Eastern Tennessee. As such, they do not reflect broader U.S. demography and cannot be extrapolated to other regional contexts. In particular, this study's sample of BIPOC donors was limited. This subsample was shaped by consensual and kin-contextualized donations to the *UTK Collection*—in turn affected by the historic mistrust of the medical and scientific communities by BIPOC donors that has led not only to a lack of reported associated information with the available BIPOC donors, but also to the majority-white modern skeletal collections seen today throughout the U.S. [24]. Due to the overall dearth of ethically sourced, modern BIPOC skeletal individuals available for forensic analysis, all BIPOC individuals in the *UTK Collection* were grouped together in one sample. However, BIPOC are far from a uniform demographic group in the U.S., or in any other sociocultural context. Unlike the sample's white individuals, whose lives likely included a relatively homogenous experience of whiteness in the modern U.S., the BIPOC sample was comprised of individuals who reported affinity with multiple populations, including African, Asian, Indigenous American, Latin American, European—and combinations thereof (e.g., "biracial" donors). While living in a racist society subjects all BIPOC to racism, this occurs to varying degrees, and trying to access those specific degrees is difficult in a small sample. Thus, this study's combined BIPOC sample may obfuscate the true nature or severity of individual experiences of embodiment and premature aging reflected in the results. Particularly, without adequate documentation for the sample's BIPOC donors, an examination of intersectionality (e.g., between race and SES) was not possible.

Yet, despite these problems with the BIPOC subsample, the tooth-presence-count data demonstrated that high-SES white donors did have statistically significantly more teeth than the BIPOC subsample, as well as their low-SES white counterparts. Tooth-count data will be a helpful avenue for future research for identifying not only dentition-wide trends, but in examining what teeth and/or region of the dentition are being retained or lost most frequently. This information could potentially help researchers better understand the lived experiences that lead to the postmortem dentition. Future research should also incorporate an individual-level approach to the many factors contributing to AMTL—both biological (e.g., age, heredity, oral environment) and socially structured (e.g., access to dental care). Forensic anthropologists are well poised to undertake these individualized analyses.

It is important, also, to acknowledge that family reported childhood SES is subjective to the reporter; in essence, it may not reflect the reality of the donor's lived experience. Childhood SES is also not directly causative of adult SES, or adult health, although it is certainly influential. Epigenetic and epidemiologic research has shown that lower-SES children experience poorer health in childhood that can be embodied during periods of development with lasting effects into adulthood [93]. Socioeconomic disadvantage experienced in childhood has been identified as a predictor of cardiovascular health [94,95], major depression [96], and poor mental executive functioning in adults [97]. Yet [98], have shown that some effects of low childhood SES can be ameliorated through education and financial success, allowing individuals and families to raise their SES. Consequently, higher SES correlates with better access to high quality resources and the alleviation of psychosocial stressors surrounding income, food, and housing insecurity. Though, it is still unknown which pathways—environmental, behavioral, psychological, physiological, or combinations thereof—produce poor adult health trajectories and outcomes [94]. This illustrates the value of utilizing ethnographic evidence in future weathering research in order to test and observe hypotheses and associations *in vivo*.

Future research on the skeletal evidence of weathering would benefit from inter-regional study of large, intentionally constructed subgroups that enable a finer-grained understanding of how lived experiences may impact premature skeletal/dental aging (e.g., impacts of childhood SES, adult SES, physical labor, differing experiences of race). Additionally, future studies may be enriched by taking a more top-down approach whereby specific bodily processes or pathological conditions are traced to skeletal evidence, as opposed to beginning at the skeleton and tracking backwards. This approach could possibly yield a more nuanced understanding of how weathering impacts the body wholly and lend insight to physiological pathways by which experiences may become embodied at the individual level. Proceeding in this direction may rely on anonymized CT data contextualized by demographic and life-history data provided by consenting donors and families [99]. Indeed, CT-based research within a structural vulnerability framework has already begun, with the University of West Florida's Structural Vulnerability Profile (SVP) project aimed at identifying and interpreting potential skeletal and dental biomarkers of lived social inequity visible in forensic case decedents [55].

Finally, while we argue the relevance of this study to forensic anthropology, our study sample is not medicolegal in nature, instead originating from self- and kin donations. Future research on the potential for AMTL to act as a biomarker of poverty should utilize ethically sourced forensic collections in order to generate and analyze frequencies of AMTL specific to forensic samples. Yet, the fact that socially structured patterns of AMTL are discernible even in a donated skeletal collection is remarkable, as it speaks to the embodiment of violence in the broader U.S. sociocultural context.

5. Conclusions

The results of this study provide some support that *weathering* (i.e., premature aging, *sensu* [16]) operates at the level of the dental tissues, possibly tracking class-based inequities and experiences of poverty and precarity [14]. Precarity is often contextualized as a labor condition characterized by temporary, unstable working conditions that offer no form of social benefits [100]. Employment in the U.S. has significantly changed over the last 50 years, with substantial decreases in full-time jobs that offer adequate salaries and benefits [101]. Women and BIPOC populations in the U.S. have experienced a steady decrease in employment quality since the 1970s [101]. Thus, these populations have disproportionately experienced precarious jobs and in consequence, the negation of social safety nets like insurance benefits and retirement funds. Even with public insurance eligibility expansions, the U.S. dental care system has little capacity to serve all patients [84]. As a response to an over-capacitated system and persons in need of dental care, proposals have been made to allow mid-level care providers, such as dental hygienists, to take on intermediate care roles within education systems and geriatric care facilities [80,83]. In this new system of care, mid-level care providers could work within school and nursing home clinics to offer dental cleanings and low-risk procedures such as dental fillings on a regular basis [80,83]. Yet, this system has yet to be fully realized, facing opposition from general dentists in Tennessee, specifically [80].

Among 183 skeletal donors from Eastern Tennessee, the low-SES white subsample had significantly more AMTL, as well as younger ages of dental attrition, than both high-SES white and BIPOC individuals when assessed via the presence of occlusal support zones. When assessed via tooth-presence counts, high-SES white individuals displayed significantly less AMTL than low-SES white and BIPOC individuals. These differences may reflect the structural, symbolic, and everyday violence through which poverty, drug use, and poor dental health are normalized in the contemporary U.S. Through this normalization, poor people

having fewer teeth becomes a naturalized condition and a marked class signifier whereby everyday violence can operate unnoticed. By masking socially meaningful differences in the embodied experiences of our case decedents, forensic anthropologists may also be contributing to post-mortem violence. If so, we must explore how our casework and reporting strategies may be rectified to accurately and sensitively record decedents' lived experiences of violence, making them legible in an official capacity [55]. Forensic anthropologists are uniquely posed to view these violences in our practice. Only with tactful and appropriate reporting methods can we perform compassionate death care for the case decedents we serve.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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