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TECHNICAL NOTE

ANTHROPOLOGY

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Investigations Into Age-related Changes in the Human Mandible*,†

ABSTRACT: While changes in mandibular shape over time are not widely recognized by skeletal biologists, mandibular remodeling and associated changes in gross morphology may result from a number of causes related to mechanical stress such as antemortem tooth loss, changes in bite force, or alterations of masticatory performance. This study investigated the relationship between age-related changes and antemortem tooth loss in adult humans via dry bone measurements. This study examined 10 standard mandibular measurements as well as individual antemortem tooth loss scores using the Eichner Index from a total of 319 female and male individuals with ages ranging from 16 to 99 years. Results indicate that few mandibular measurements exhibited age-related changes, and most were affected by antemortem tooth loss.

KEYWORDS: forensic science, forensic anthropology, mandible, aging, edentulism, osteometrics

Age-related skeletal changes in adults have been well documented in a number of skeletal elements, most commonly the pubic symphysis of the innominate, and the sternal ends of the fourth ribs (1,2). Recently, Shaw et al. (3) argued that the gross morphology of the adult mandible changes significantly with age; their project being an expansion of a pilot study with similar results by Pessa et al. (4). While changes in mandibular shape over time are not widely recognized by skeletal biologists, mandibular remodeling and associated changes in gross morphology may result from a number of causes related to mechanical stress such as antemortem tooth loss, changes in bite force, or alterations of masticatory performance (Fig. 1). This study highlights the need for consideration of other factors that may affect skeletal morphology when attempting to correlate morphological change with age.

It has been well documented that edentulous individuals produce lower bite forces compared to those individuals with full dentition, including cases in which complete dentures were worn (5–8). Those with intermediate degrees of tooth loss also produce lower maximum bite forces and exhibit a reduction in overall masticatory performance in comparison with fully dentate individuals (7,9,10). However, rather than the total number of teeth present, the number of occlusal contacts is more highly correlated with bite force, explaining 10–20% of the variation in maximum bite force in adults. Additionally, tooth loss in the posterior region of the dentition has been found to result in a greater reduction in maximum bite force compared to the loss of the anterior teeth (5).

Hatch et al. (11) examined various factors that may affect masticatory performance, which was assessed using a modified Mastication Performance Index (MPI). This index assesses chewing efficiency in dentate subjects by measuring the percentage of a test food bolus that will pass through a sieve after a set number of masticatory cycles. The variables considered that may affect masticatory performances included bite force, age, the number of functional tooth units (i.e., occlusal pairs), sex, masseter cross-sectional area, the presence of temporomandibular joint disorders, and the presence of diabetes mellitus. Hatch et al. (11) found that the number of postcanine functional occlusal pairs was the best predictor of masticatory performance, while the direct effect of age on both masticatory performance and the number of functional occlusal pairs was slight. Thus, the reduction in muscular activity and bite force secondary to tooth loss might affect the morphology of the mandible, particularly in the alveolar region and in areas of masticatory muscle attachment.

This mandibular morphological change may result from growth and remodeling in response to mechanical stress. In general, bone cells adapt to a routine loading environment, which makes them less responsive to regular habitual loading signals. Abnormal strains, including forces that are lower than normal, can cause microstructural changes in bone which then, in turn, result in gross morphological changes (12). Frost's Mechanostat Theory suggests that there is a minimum effective strain in bone which needs to be exceeded for an adaptive response to occur; thus, there is a range of strain values that will not stimulate any adaptive response (13). Others have referred to this range as the "lazy zone," for which a range of tissue stresses will stimulate only slight bone apposition or resorption, whereas stresses outside this zone will result in rapid bone apposition or resorption (14). Therefore, mandibular morphological changes attributed to aging may result from a reduction in mechanical forces secondary to antemortem tooth loss.

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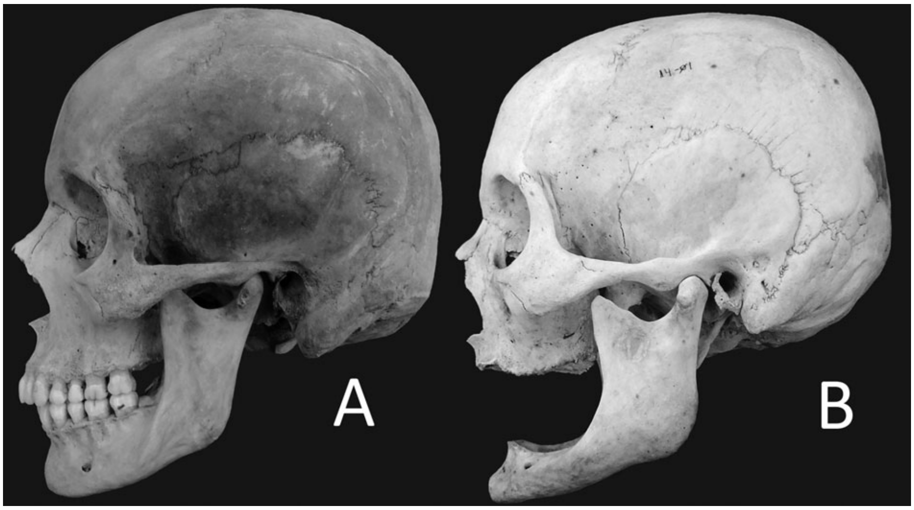

FIG. 1—*Skull exhibiting complete occluding dentition (excluding third molar agenesis) (A) and skull exhibiting complete antemortem tooth loss and related alveolar bone resorption (B) (Note, skulls are not to scale).*

Aside from this biomechanical influence, antemortem tooth loss may also affect mandibular morphology through the stimulation osteoclastic activity, which results in bone resorption along the alveolar crest. Even after the open alveolar socket is healed through localized remodeling, a phenomenon called residual ridge reduction results in the continual resorption of alveolar bone throughout life (15). This alveolar ridge resorption occurs even in cases where dentures are worn to improve masticatory function (16).

Alleged age-related mandibular changes in shape were identified by Shaw et al. (3) using a sample of CT scans from 60 males and 60 females. From these CT scans, Shaw et al. (3) examined six mandibular measurements and found that as both male and female individuals aged, there were significant decreases in Maximum Ramus Height, Mandibular Body Height (equivalent to Chin Height using the Forensic Data Bank definitions, see 17—the latter term will be used here for consistency), and Mandibular Length, as well as increases in the Mandibular Angle. Although edentulous individuals were excluded in this study, Shaw et al. (3) did not attempt to control for intermediate degrees of antemortem tooth loss, nor did they utilize the full set of standard mandibular measurements (18). The goal of this paper is to use similar methods as Shaw et al. (3) on a larger sample and to control for antemortem tooth loss to further investigate adult mandibular age-related morphological changes.

Materials and Methods

To more fully investigate the purported mandibular age-related changes, the authors used a sample of 319 individuals from the William M. Bass Donated Skeletal Collection (n = 163) at the University of Tennessee Knoxville and the Robert J. Terry Anatomical Skeletal Collection (n = 156) at the Smithsonian National Museum of Natural History. The sample consisted of 105 females with ages ranging from 17 to 99 years and 214 males with ages ranging from 16 to 84 years (total n = 319) (Table 1).

A single observer (Dr. Skorpinski) collected the ten standard mandibular measurements (18) and scored antemortem tooth loss according to the Eichner Index, which classifies tooth loss based on the presence of occlusal pairs (9,19) (see Table 4 below for measurement details). This classification system treats the molars, premolars, and anterior teeth as separate occlusal support zones. Using this index, previous studies have indicated a reduction in maximum occlusal force and masticatory performance accompanying a greater loss of occlusal contacts (9,10).

TABLE 1—*Breakdown of females and males in each age category.*

	Young Adults <40 years	Middle Adults 41–64 years	Old Adults >65 years
Females (n)	34	51	20
Mean age (years)	32.4	53.2	74.3
Standard Deviation	17.2	6.8	13.5
Males (n)	52	144	18
Mean age (years)	32.4	51.2	70.8
Standard Deviation	12.7	6.3	4.9

A two-way analysis of variance (ANOVA) was performed using R (20) to determine whether age, the Eichner Index (scored as 1, 2, or 3, representing Eichner Index scores of A, B, or C, respectively), and the interaction between the two variables had an effect on the mandibular measurements. All analyses were run independently for female and male individuals due to well-known size differences based on sexual dimorphism (see 21 and references therein). For the ANOVA analyses, age at death was broken into a three categorical variables representing Young Adults (<40 years), Middle Adults (40–59 years), and Old Adults (>60 years). These age categories are identical to those used by Shaw et al. (3) for the purpose of consistency and replicability. The Eichner Index was also a three-stage categorical variable with "A" representing the presence of all four posterior occlusal support zones; "B" representing the presence of one to three posterior occlusal support zones, or support in the anterior area only; and "C" representing the absence of all occlusal support zones (see 9,19) for more information) (Fig. 2).

Results

Because individuals from the Terry Collection and WM Bass Collection are separated temporally by ~75 years, secular changes in mandibular body size may likely have occurred (23) potentially affecting the measurements of the individuals in each

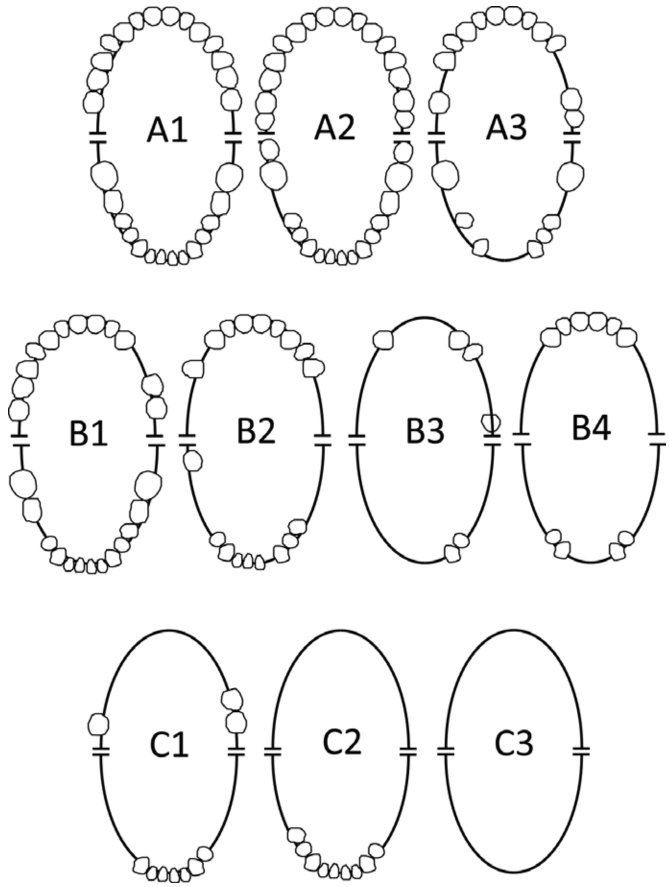

FIG. 2—*Diagrams representing stages A, B, and C of Eichner Index occlusal support zones (recreated from 22).*

TABLE 2—*Spearman correlations of all variables to Eichner Index.*

Variable	Eichner Index
Age (years)	0.404
Age (category)	0.411
Chin Height	−0.347
Height of the Mandibular Body	−0.372
Breadth of the Mandibular Body	−0.225
Bigonial Breadth	0.107
Bicondylar Breadth	0.186
Minimum Ramus Breadth	−0.148
Maximum Ramus Breadth	−0.142
Maximum Ramus Height	0.030
Mandibular Length	−0.036
Mandibular Angle	0.160

sample. However, ANOVA tests were run on each sample independently and produced similar results in both samples as well as when they were pooled into a single sample; thus, all results are presented with the total combined dataset.

Table 2 presents Spearman's correlations between each variable and the Eichner Index (all significant at the $p < 0.05$ level), Table 3 presents ANOVA significance values for each variable, and Table 4 presents the descriptive statistics for all measurements. Results found that the Eichner Index is moderately positively correlated with age and moderately negatively correlated with Chin Height and Height of the Mandibular Body, and all other correlations were weak. Additionally, significant differences in measurements relative to the Eichner Index were found in both female and male groups for Chin Height and Height of the Mandibular Body only.

TABLE 3—p-*value summaries from ANOVA analyses.*

Mandibular Measurement	Age	Eichner Index	Age*Eichner Index
Chin Height			
Females	0.284	**0.014**	0.956
Males	0.692	**<0.001**	0.083
Body Height			
Females	**0.042**	**0.017**	0.527
Males	0.402	**<0.001**	0.280
Body Thickness			
Females	0.100	0.530	0.528
Males	0.437	**<0.001**	0.903
Bigonial Breadth			
Females	0.786	0.106	0.370
Males	**0.046**	0.707	0.155
Bicondylar Breadth			
Females	0.075	0.804	0.919
Males	**0.007**	0.528	0.394
Minimum Ramus Breadth			
Females	0.109	0.782	0.973
Males	0.061	**<0.001**	0.618
Maximum Ramus Breadth			
Females	0.171	0.242	0.900
Males	**0.012**	**<0.001**	0.094
Ramus Height			
Females	0.228	0.333	0.327
Males	0.161	0.059	0.161
Mandibular Length			
Females	0.443	0.652	0.892
Males	0.681	**0.012**	0.180
Mandibular Angle			
Females	0.937	0.541	0.893
Males	0.345	**0.001**	0.632

Significant differences in bolded font.

Three mandibular measurements: Bigonial Breadth, Bicondylar Breadth, and Maximum Ramus Breadth were found to vary significantly with age, but only for males ($p < 0.05$, in all instances). Height of the Mandibular Body also varied significantly with age in females; however, no measurements varied significantly with age for both females and males. Analysis of the Eichner Index found significant differences in males only for Breadth of the Mandibular Body, Minimum Ramus Breadth, Maximum Ramus Breadth, Mandibular Length, and Mandibular Angle. No significant differences were found with the interaction of age *and* the Eichner Index for any measurements.

Discussion/Conclusions

The current study investigated changes in mandibular measurements in adult humans via dry bone measurements from two collections totaling 319 female and male individuals with ages ranging from 16 to 99 years. This study found that few mandibular measurements exhibited age-related changes, and most were affected by antemortem tooth loss. Bigonial Breadth, Bicondylar Breadth, and Maximum Ramus Breadth increased with age, and Mandibular Length and Mandibular Angle increased with antemortem tooth loss for males. All other significant differences reflect decreases in the variables.

Shaw et al. (3) found the Maximum Ramus Height, Chin Height, and Mandibular Length all changed significantly with age for both males and females, and in all cases, their measurements decreased. Within our sample, we found no significant changes in Maximum Ramus Height. We also found that Mandibular Length changed significantly for males, but only due

TABLE 4—*Measurement breakdown (all measurements in mm, mandibular angle in degrees).*

	Eichner Index - A			Eichner Index - B			Eichner Index - C		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
Chin Height									
Females									
YA	31.1	3.3	32.0	30.0	4.2	2.0	N/A	N/A	0.0
MA	29.9	3.7	31.0	30.1	3.8	18.0	22.0	N/A	1.0
OA	29.1	4.9	8.0	29.2	4.6	10.0	23.0	0.0	2.0
Males									
YA	33.7	3.4	45.0	33.4	2.7	6.0	N/A	N/A	0.0
MA	34.0	4.0	73.0	32.9	4.7	30.0	27.1	4.8	41.0
OA	33.3	1.1	2.0	35.4	4.4	8.0	23.1	5.7	8.0
Height of the Mandibular Body									
Females									
YA	29.2	2.6	32.0	30.0	1.4	2.0	N/A	N/A	0.0
MA	27.7	3.0	31.0	28.9	3.6	18.0	21.0	N/A	1.0
OA	27.6	3.7	8.0	26.6	2.8	10.0	23.0	2.8	2.0
Males									
YA	31.7	3.0	45.0	29.8	2.0	6.0	N/A	N/A	0.0
MA	31.9	2.9	73.0	30.1	2.6	30.0	24.9	5.2	41.0
OA	31.4	2.3	2.0	32.0	3.1	8.0	22.6	5.4	8.0
Breadth of the Mandibular Body									
Females									
YA	11.8	2.0	32.0	13.5	0.1	2.0	N/A	N/A	0.0
MA	11.6	1.9	31.0	12.1	1.9	18.0	10.0	N/A	1.0
OA	11.0	1.3	8.0	10.8	1.1	10.0	11.0	0.0	2.0
Males									
YA	11.9	2.0	45.0	11.1	1.4	6.0	N/A	N/A	0.0
MA	12.3	1.7	73.0	11.7	1.8	30.0	10.7	1.0	41.0
OA	11.7	0.5	2.0	11.9	1.3	8.0	10.8	1.1	8.0
Bigonial Breadth									
Females									
YA	90.1	5.8	32.0	96.0	4.2	2.0	N/A	N/A	0.0
MA	91.1	5.8	31.0	92.2	5.8	18.0	90.0	N/A	1.0
OA	92.5	4.1	8.0	91.7	3.2	10.0	83.0	2.8	2.0
Males									
YA	98.9	6.9	45.0	93.5	7.3	6.0	N/A	N/A	0.0
MA	99.6	6.0	73.0	100.2	6.9	30.0	98.7	6.5	41.0
OA	102.2	4.5	2.0	100.5	8.6	8.0	104.5	5.4	8.0
Bicondylar Breadth									
Females									
YA	109.0	6.2	32.0	109.0	4.2	2.0	N/A	N/A	0.0
MA	111.7	4.9	31.0	112.3	6.0	18.0	110.0	N/A	1.0
OA	112.8	3.8	8.0	111.1	6.4	10.0	109.5	5.0	2.0
Males									
YA	115.7	5.6	45.0	113.1	4.9	6.0	N/A	N/A	0.0
MA	116.8	6.1	75.0	118.8	5.1	30.0	17.7	6.1	41.0
OA	121.3	3.8	2.0	122.6	6.2	8.0	120.8	6.1	8.0
Minimum Ramus Breadth									
Females									
YA	30.1	3.9	32.0	31.0	8.5	2.0	N/A	N/A	0.0
MA	29.3	3.9	31.0	29.8	3.2	18.0	30.0	N/A	1.0
OA	28.0	2.2	8.0	27.8	2.8	10.0	29.5	0.7	2.0
Males									
YA	32.6	3.9	45.0	29.9	2.3	6.0	N/A	N/A	0.0
MA	32.1	3.5	75.0	31.1	2.7	30.0	29.1	3.5	41.0
OA	33.3	0.4	2.0	32.4	3.8	8.0	32.1	2.9	8.0
Maximum Ramus Breadth									
Females									
YA	41.0	3.3	32.0	41.0	4.2	2.0	N/A	N/A	0.0
MA	42.0	3.8	31.0	41.7	4.0	18.0	46.0	N/A	1.0
OA	41.1	3.3	8.0	39.5	2.7	10.0	43.0	0.0	2.0
Males									
YA	44.5	3.8	45.0	41.1	2.7	6.0	N/A	N/A	0.0
MA	44.7	3.9	75.0	44.1	3.0	30.0	41.1	3.2	41.0
OA	45.6	9.1	2.0	44.7	5.1	8.0	46.1	4.1	8.0
Maximum Ramus Height									
Females									
YA	56.8	4.0	32.0	52.5	9.2	2.0	N/A	N/A	0.0
MA	57.9	4.7	31.0	58.5	4.2	18.0	58.0	N/A	1.0
OA	58.0	3.7	8.0	58.6	4.0	10.0	51.5	2.1	2.0

TABLE 4—*Continued.*

	Eichner Index - A			Eichner Index - B			Eichner Index - C		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
Males									
YA	64.6	4.9	45.0	59.5	4.6	6.0	N/A	N/A	0.0
MA	65.2	4.7	75.0	64.7	3.5	30.0	63.7	4.4	41.0
OA	66.0	4.2	2.0	66.1	5.1	8.0	63.6	5.0	8.0
Mandibular Length									
Females									
YA	74.3	5.5	32.0	76.0	7.1	2.0	N/A	N/A	0.0
MA	73.6	5.8	31.0	73.2	5.5	18.0	78.0	N/A	1.0
OA	73.0	3.4	8.0	71.5	4.6	10.0	74.0	1.4	2.0
Males									
YA	77.5	6.3	45.0	78.1	6.8	6.0	N/A	N/A	0.0
MA	78.3	5.9	75.0	80.2	5.0	30.0	75.1	5.4	41.0
OA	77.5	2.1	2.0	78.1	9.0	8.0	80.1	6.7	8.0
Mandibular Angle									
Females									
YA	124.2	7.1	32.0	128.0	17.0	2.0	N/A	N/A	0.0
MA	124.8	8.4	31.0	125.6	6.5	18.0	132.0	N/A	1.0
OA	125.1	4.0	8.0	124.6	5.9	10.0	128.0	2.8	2.0
Males									
YA	123.3	7.3	45.0	127.3	6.7	6.0	N/A	N/A	0.0
MA	123.2	7.2	75.0	123.8	6.8	30.0	127.8	6.4	41.0
OA	117.5	3.5	2.0	123.4	7.0	8.0	124.9	8.8	8.0

to antemortem tooth loss as quantified by the Eichner Index. Chin Height changed significantly for both females and males following antemortem tooth loss, but did not change with age.

Generally, these findings are consistent with previous studies examining the relationship between antemortem tooth loss and mandibular morphology. Specifically, edentulism has been associated with mandibular bone resorption and loss of vertical height of the mandibular body (24–29). Age by itself has not been significantly correlated with mandibular body height (26). In a skeletonized sample from the Netherlands, Mays (30) found a negative association between mandibular body height and age, but only in areas where the tooth was lost antemortem at the position of the measurement. Therefore, tooth loss, rather than age, appears to have a significant influence on mandibular body height.

Most studies suggest that antemortem tooth loss is associated with a widening of the gonial angle (25,31–36). Additionally, some have found little to no relationship between gonial angle and age (29,34,35). Ceylan et al. (37) found no significant differences in gonial angle between completely edentulous individuals and individuals with unilateral tooth loss in the posterior region, although no completely dentate group was included for comparison. Ohm and Silness (35) found that partially edentulous individuals exhibited gonial angle measurements in between those of completely dentate and completely edentulous individuals. These studies suggest that intermediate degrees of antemortem tooth loss may significantly impact mandibular morphology. The effects of denture-wearing on the gonial angle seemed to be mixed, however. Ceylan et al. (37) found that those who wore dentures to improve masticatory function exhibited gonial angles that were not significantly different from nonwearers. In a longitudinal study, Yanikoglu and Yilmaz (36) found that after an initial post-tooth extraction widening, the gonial angle returned to its initial value after several years of wearing dentures; however, the sample size for this study was very small ($n = 20$).

Although intermediate degrees of tooth loss explain much of the findings by Shaw et al. (3), this study did not find a relationship between antemortem tooth loss and height of the ramus. This is consistent with studies by Merrot et al. (25) using radiographs and by Ozturk et al. (28) using skeletonized mandibles. However, other studies have found decreases in ramus height with increasing degrees of antemortem tooth loss. Huumonen et al. (32) examined a sample of panoramic radiographs of 1036 individuals who ranged in age from 60 to 78 years. Mandibular morphology of edentulous individuals was compared to dentate individuals, who were defined by the presence of at least one intact tooth or dental implant. Edentulous subjects exhibited smaller condylar height, measured from most posterior point on the condyle to a line tangent to most superior point on condyle, and a smaller ramus height, measured as the distance between two most posterior points on ramus. Although the sample in this study was large, the authors' broad definition of "dentate" likely resulted in a portion of the "dentate" group possessing similar masticatory function as those classified as edentulous. A more recent study by Joo et al. (33) addresses this limitation by comparing completely edentulous individuals to those with all teeth but the third molar. Using the same measurements as Huumonen et al. (32) on panoramic radiographs of 240 individuals ranging in age from 60 to 69 years, edentulous individuals were found to have smaller condylar height on the left side. Smaller ramus height was also observed on the left side for edentulous females, but not males (33). An additional study by Chrcanovic et al. (31) found a reduction in ramus height using skeletonized mandibles in edentulous individuals, although this reduction was also more pronounced in females.

Differences in approach may also account for discrepancies between this study and that of Shaw et al. (3). It is not clear how applicable measurements meant for dry skeletonized mandibles are for three-dimensional CT scan data. In particular, Mandibular Length and Maximum Ramus Height are meant to be taken with a mandibulometer (18).

Our results were generally consistent with those found by other researchers. It is widely known that socioeconomic gaps leave a large portion of the population without access to proper dental care, and as such, antemortem tooth loss and subsequent mandibular shape changes may begin at an earlier age and result in more extreme morphological changes in these individuals. Additionally, such morphological changes may not occur or may be significantly delayed for those with better access to dental care. The general trends we identified are largely consistent with those found in other populations; however, investigations as to when antemortem tooth loss and its related changes occur have yet to be conducted. Given these findings, it may be necessary to re-evaluate previous notions of mandibular morphological change and age, as much of these are likely more a consequence of antemortem tooth loss associated with dental health than increased senility.

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