MINDING THE GAPS: A METHODOLOGICAL APPROACH TO INTER-INDIVIDUAL VARIABILITY IN SKELETAL COMPLETION

Jess L. Beck

In order to ensure sufficient sample sizes, bioarchaeological studies of individual health in prehistory must often rely on assemblages that demonstrate high inter-individual variability in skeletal completion. Determining whether higher insult frequencies in particular individuals result from their greater skeletal preservation is a key step in understanding ancient health and disease. This study uses a simple new z-score residual approach to control for inter-individual differences in skeletal completion while comparing multiple variables. To test this method, a sex- and age-balanced sample of 85 adult individuals was selected from five Middle and Late Woodland sites in Illinois: Helton (11GE540), Gibson (11C5), Ledders (11C132), Ray (11BR104,) and Carter (11GE624). Data on the frequency of nine different health indicators were collected, and statistically significant period- or sex-based differences in osteoarthritis, alveolar resorption, and hypoplasias were observed, illustrating the utility of this approach for bioarchaeologists concerned with the effects of skeletal completion on assessments of prehistoric health.

Las investigaciones bioarqueológicas sobre la salud del individuo en la prehistoria frecuentemente se basan en conjuntos que demuestran una alta variabilidad interindividual en la preservación del esqueleto para garantizar tamaños de muestras suficientes. Un aspecto clave para comprender la salud y las enfermedades antiguas es determinar si las frecuencias más altas de patologías en ciertos individuos son el resultado de su mayor preservación en el esqueleto. Esta investigación compara múltiples variables utilizando una nueva y sencilla aproximación residual z-score para controlar las diferencias interindividuales en la preservación del esqueleto. Para poner a prueba este método se seleccionó una muestra de sexo y edad balanceada de 85 individuos de cinco sitios del Woodland medio y tardío en Illinois – Helton (11GE450), Gibson (11C5), Ledders (11C132), Ray (11BR104) y Carter (11GE624). Se recogieron datos sobre la frecuencia de nueve indicadores de salud y se observaron diferencias estadísticamente significativas basadas en el período o el sexo para la osteoartritis, la resorción alveolar y la hipoplasia, lo cual demuestra la utilidad de esta aproximación para los bioarqueólogos interesados en los efectos del esqueleto completo en las evaluaciones de la salud prehistórica.

Due to the combined effects of taphonomic destruction, variable excavation strategies, and differential mortuary practices, most bioarchaeological samples are characterized by "gaps," meaning that the full range of skeletal elements is not present for each individual. However, prehistoric samples are often small at the outset, so limiting studies to individuals that preserve only the same skeletal elements is not a feasible solution to this problem. Accordingly, to rigorously examine individual health in prehistory, bioarchaeologists must develop strategies to maximize the amount of information recoverable from samples characterized by variability in skeletal completion.

This report provides a simple z-score residual method for controlling for inter-individual variability in skeletal completion within a given sample. It presents a significant contribution to bioarchaeological methodology in that it is capable of (1) investigating the nature of the interrelationships between health indicators in a sample, while (2) controlling for variability in the level of skeletal completion between individuals. Additionally, by examining health indicators like enamel hypoplasias, it offers a window into childhood health and well-being, providing the ability to contrast markers of adult status with an individual's treatment during youth. Finally, the approach highlighted here may have value to archaeologists

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working with other material remains that are subject to variable preservation.

Here, the z-score residual approach is evaluated against the rich bioarchaeological backdrop of the lower Illinois River Valley and is used to compare subsamples of different chronological periods and sexes. In this region, past research has focused on specific components of health (e.g., Cook and Buikstra 1979; Goodman et al. 1980), using large samples of individuals from different skeletal series. In contrast, this study collects data on multiple health indicators from the same sample of individuals, allowing for a controlled analysis of diachronic change in health-related variables. The preliminary test of this method on a small sample of individuals demonstrates an application of the z-score residual method to bioarchaeological material and illustrates its potential utility for researchers concerned with controlling for inter-individual variability in skeletal samples.

The Sample

Individuals were sampled from five sites in the lower Illinois River Valley (Figure 1). The Helton (11GE540), Gibson (11C5), Ledders (11C132), Ray (11BR104), and Carter (11GE624) sites are located in Greene, Brown, and Calhoun counties in close geographic proximity to one another (Flotow 2006; Lambert et al. 1979; Perino 2006). Carter Mound 1, Gibson, and Ray are Middle Woodland sites dated to approximately cal A.D. 0–411 (Jason King, personal communication 2012; King et al. 2011), while Carter Mound 2, Helton, and Ledders are Late Woodland sites dated to 904–1272 cal A.D. (Conner 1984; Jason King, personal communication 2012; Tainter 1975).

Data Collection

Data were collected on nine different health indicators for 85 individuals.[1] This sample of individuals was selected with four goals in mind: (1) maximizing skeletal completion; (2) balancing categorical age groups; (3) incorporating equal numbers of male and female individuals in each age category; and (4) maintaining an equal distribution between sites and time periods (Table 1). Age and sex had previously been estimated for all individuals by researchers at the Center for American Archeology, using standard bioarchaeological procedures, as outlined in Buikstra and Ubelaker (1994). Only adult individuals were included in this sample due to the late developmental appearance of sexually dimorphic skeletal features in humans. Estimated age ranges were collapsed into three categories for the purposes of this study, using categories drawn from Buikstra and Ubelaker (1994). "Young adults" were individuals whose midpoint fell between 20–35 years, "middle adults" had a midpoint between 35–50 years, and "old adults" had midpoints estimated to be greater than 50 years.

The preliminary selection of individuals was based on a visual assessment of completeness. Subsequent quantitative bioarchaeological assessments of skeletal, dental, and alveolar completion supported this method. Skeletal completion was calculated with reference to the Inventory Recording Form for Complete Skeletons from Buikstra and Ubelaker (1994:Attachment 1, Chapter 2).

To calculate percentage of skeletal completion for sampled individuals, "complete" elements were given a percentage score of 1, "partial" elements were given a score of .50, and "poorly preserved" elements were given a score of .25. When calculating skeletal completion, each element was weighted equally. The elements present for each individual were tallied, and each individual was given a score out of a total of 91 bones (Table 2).

The entire sample was left-skewed as a result of the deliberate selection of more complete skeletal remains for data collection (Shapiro Wilks W = .942944, p = .0009). A nonparametric Kruskal-Wallis test performed in the statistical package JMP found no significant differences in the degree of skeletal completion between the period-sex subsamples (MWF = Middle Woodland Female, MWM = Middle Woodland Male, LWF = Late Woodland Female, and LWM = Late Woodland Male) (Kruskal-Wallis χ^2 = 4.0050; df =3; p = .2609), or between collapsed period samples (MW, LW) (Wilcoxon χ^2 = 1.2858; df = 1; p = .2568).

Dental completion was calculated as a percentage out of 32 possible teeth, and was left-skewed as a result of the deliberate selection of more complete skeletal remains for data collection (Shapkiro Wilks W = .937034; p = .0004). There was a significantly lower degree of dental completion for MWF than all other period-sex subsamples

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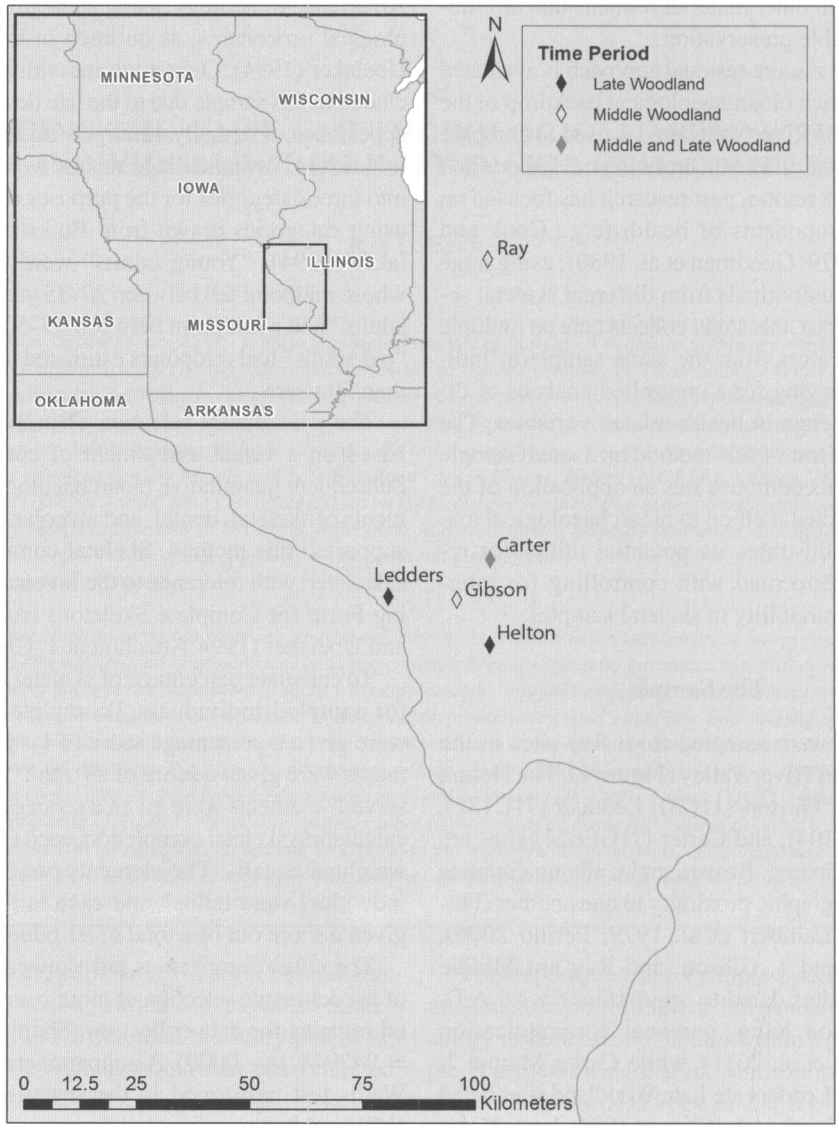


Figure 1. Location of Middle and Late Woodland sites in the Lower Illinois River Valley.

(Kruskal -Wallis $\chi^2 = 9.1431$; $df = 3$; $p = .0243$). Finally, alveolar completion was recorded as a percentage of sockets observable out of 32. Alveolar completion for the total sample was also left-skewed as a result of the deliberate selection of more complete skeletal remains (Shapiro Wilks $W = .814809$, $p < .0001$). A Kruskal-Wallis test revealed no significant differences in degree of alveolar completion between the period-sex subsamples (Kruskal -Wallis $\chi^2 = 4.0445$; $df = 2$; $p = .2567$), or the collapsed period samples (Wilcoxon $\chi^2 = .7298$; $df = 1$; $p = .3929$).

After each skeletal inventory, data on the frequency and severity of nine health indicators were collected for each individual, using guidelines outlined in Buikstra and Ubelaker (1994:107–123). These health indicators were selected based on their commensurability with previous large-scale studies and datasets (Cohen and Armelagos 1984; Steckel and Rose 2002): (1) porotic hyperostosis and cribra orbitalia, (2) abnormal bone formation, (3) abnormal bone loss, (4) osteoarthritis, (5) trauma, (6) linear enamel hypoplasias, (7) caries, (8) abscesses, and (9) alveolar resorption.

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Table 1. Sample Size by Site.

Site	♀M	♀O	♀Y	♀ Total	♂M	♂O	♂Y	♂Total	♀♂Total
Carter (M1)	2	2	1	5	2	1	1	4	9
Carter (M2)	2	0	2	4	4	0	1	5	9
Gibson	2	3	3	8	3	4	2	9	17
Helton	2	3	2	7	4	3	1	8	15
Ledders	4	2	3	9	3	3	3	9	18
Ray	3	1	4	8	5	0	4	9	17
Total	15	11	15	41	21	11	12	44	85

Note: For abbreviated age categories, M = Middle-aged, O = Old, Y = Young.

Table 2. Anatomical Regions and Related Elements.

Region	Elements	# Elements
Skull	Frontal, parietal, occipital, temporal, sphenoid, zygomatic, maxilla, palatine, mandible	13
Post-Cranial	Clavicles, scapulae, sacrum, ilia, ischia, pubes	12
Spine	Cervical, thoracic, and lumbar vertebrae	24
Upper Limb	Humeri, radii, ulnae	6
Lower Limb	Femora, tibiae, fibulae	6
Carpals	Scaphoid, lunate, triquetral, pisiform, trapezoid, trapezium, capitate, hamate	16
Tarsals	Calcaneus, talus, navicular, lateral cuneiform, intermediate cuneiform, medial cuneiform, cuboid	14
Total	91	

Note: The phalanges, metacarpals, metatarsals, ribs, patellae, auditory ossicles, and the delicate bones of the face were not used in the calculation of the skeletal completion index, as these bones do not preserve well archaeologically, are not particularly informative about the aspects of individual health examined in this study, and artificially inflate the requirements for skeletal completion.

These nine variables are grossly observable and provide holistic portraits of individual and community health and disease. Together they incorporate aspects of dental health, diet, infectious disease-related morbidity, levels of physical activity, and patterns of environmental risk and interpersonal violence, and have consequently become the focus of large-scale, collaborative investigations of diachronic changes in human health (e.g., Cohen and Crane-Kramer 2007; Steckel and Rose 2002). The import and etiology of these health indicators are more fully discussed in the archaeological and bioarchaeological literature (Cohen and Armelagos 1984; Steckel and Rose 2002).

Methods

Data collected on these nine insults were divided into two categories in order to control for differential preservation between anatomical regions. Category I comprises insults 1–5, which are affected by the preservation of the cranial and post-cranial skeleton. Category II includes insults 6–9, which are affected by the preservation of the dentition and alveolar bone. Because overall skeletal completion was favored when selecting individuals during data collection, individuals lacking dentition and/or individuals lacking alveolar bone comprise part of the sample. In contrast, all individuals sampled had at least some portion of the cranial and post-cranial skeleton present (Figure 2). Because of this variability in osteological completion, dif-

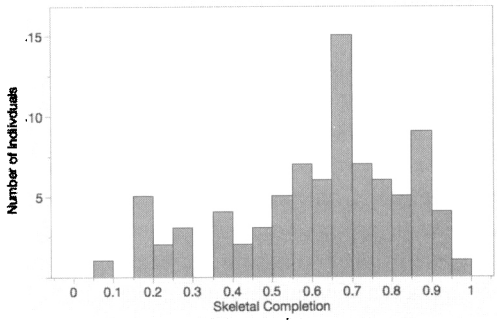


Figure 2. Histogram of skeletal completion for total sample.

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ferent statistical methods were used for Category 1 insults relative to Category 2 insults.

Methods: Category I—Skeletal Insults

Skeletal completion did not differ significantly between any period-sex or period samples, so all individuals were used to test for differences in skeletal insults, regardless of their level of skeletal completion. The number of affected bones per individual was treated as the individual's Category I score for the type of insult under investigation.

However, the effects of skeletal completion on insult preservation differed for different types of insults. For example, degree of skeletal completion was positively correlated with osteoarthritis and had a positive but non-significant relationship to abnormal bone formation[2] (Figure 3a). To control for these differential effects, skeletal insult scores were first transformed into z-scores. A z-score indicates how many standard deviations a point is from a sample mean, using the formula $z = (x - \bar{x})/s$, where x is the insult score, $\bar{x}$ is the sample mean, and s is the sample standard deviation. Z-scores make insults drawn from distributions with different ranges immediately comparable, as all insults are measured on the same scale (Figure 3b). After the z-score transform, the insult scores were regressed against skeletal completion to produce residuals. Z-score residuals take into account the effects of skeletal completion on insult count, making it possible to control for instances where insult counts are low because completion is low and where insult counts are high because completion is high. The z-score residuals represent the degree to which individuals have high or low numbers of skeletal insults, *taking into account* the effect of skeletal completion on insult count (Figure 3c).

The use of z-score residuals presents an improvement over traditional bioarchaeological reporting standards that focus solely on differences in the frequency of insults between samples. Specifically, this method is capable of controlling for the effect of skeletal completion on insult preservation. Commensurate levels of skeletal completion are rare across prehistoric skeletal samples, so differentiating between individuals who evince a low number of insults due to low skeletal completion and individuals who evince a low number of insults due to lack of affliction provides a more nuanced approach to paleopathological studies. Additionally, z-score residuals make it possible to compare different types of insults on the same scale, while still accounting for the differential effects of skeletal completion on insult preservation within each insult category.

After controlling for the differential effects of skeletal completion by using z-score residuals, a Shapiro-Wilks test was used to assess normality. The test found that all distributions of Category I insults departed significantly from normal, so a non-parametric Kruskal-Wallis test was used to test for significant differences between samples and subsamples. Finally, correlations of all Category 1 insults were run to identify whether positive, negative, or neutral relationships existed between the different categories of insults. These correlations allowed for a more fine-grained examination of prehistoric health experiences by establishing the relationships *between* health indicators. For example, correlations allowed for the establishment of whether individuals in the sample suffering from osteoarthritis were at higher or lower risk for abnormal bone formation, or whether there was no relationship between the two insults.

Methods: Category II—
Dental and Alveolar Insults

Individuals who lacked dentition or alveolar bones were removed from the sample, slightly reducing sample sizes (Table 3). This removed "meaningless zeros" from the analysis (i.e., individuals who preserved zero caries because they preserved no dentition). Then, counts of dental and alveolar insults were transformed into z-scores using the mean and standard deviation for the entire available sample. Z-scores were used instead of insult counts because dental completion differed significantly between period-sex samples, a disparity that needed to be addressed before examining differences between subsamples, and the distributions of alveolar insults had markedly different ranges (abscesses had a maximum count of 5, resorption had a maximum count of 26), and so z-scores were used to make scores for abscesses and resorption comparable on the same scale (see Figure 3b).

Z-scores for each insult were regressed against dental completion or alveolar completion as appropriate in order to produce residuals. The z-

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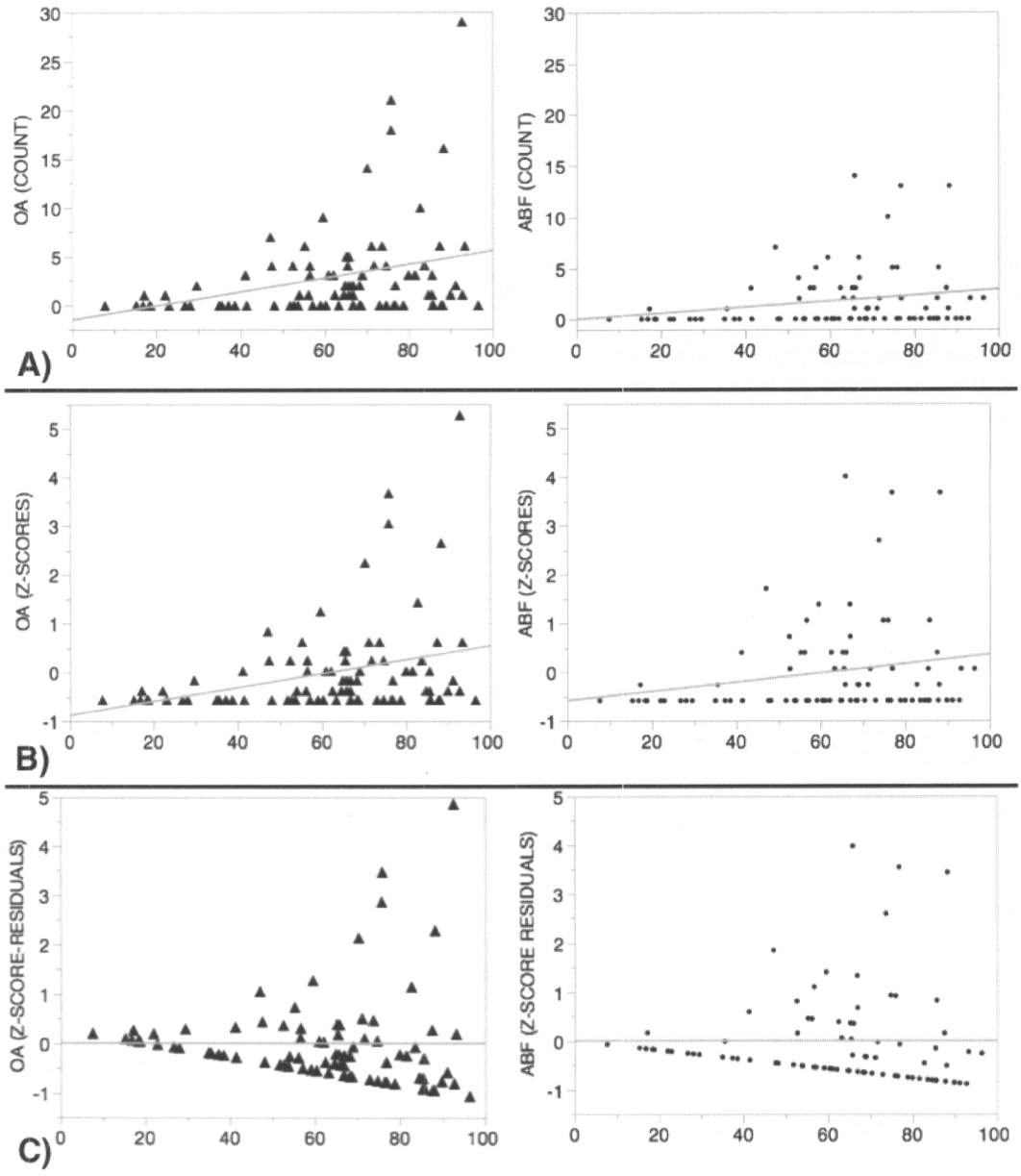


Figure 3. Insult transformations for osteoarthris (OA) and abnormal bone formation (ABF). X-axis shows percentage of skeletal completion: a) original count data - note the different distributional spreads and strength of relationship to skeletal completion; b) Z-score transformation, where the spread of the points is comparable as measurements are weighted relative to sample means and standard distributions; c) Z-score residuals, which shows how high or low insult counts.

score residuals were used to test for normality because they identified individuals who had far more or far fewer insults than expected *given* the relationship between skeletal completion and insult count for that particular insult. Residuals of the regression of insult z-scores by completion were tested for normality using a Shapiro-Wilks test. The majority of sample distributions were right skewed, so a non-parametric Kruskal-Wallis test was used to compare insults between samples.

Finally, bivariate relationships between dental insults and alveolar insults were examined to ex-

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Table 3. Sample Size for Each Category 2 Insult.

Category	MWF	MWM	LWF	LWM	Total n
Dental Insults	21	21	19	22	83
Alveolar Insults	20	22	19	21	82

plore whether experiencing one insult made individuals significantly more or less vulnerable to other insults. These correlations revealed whether individuals who had a higher number of abscesses than predicted, given their alveolar completion, also had higher numbers of resorbed sockets, and whether individuals with higher numbers of dental caries than expected also suffered from higher numbers of hypoplasias.

Results

Results: Category 1—Skeletal Insults

Insult Categories 1, 3, and 5 were observed at such low frequencies in the sample population that further analysis would not be informative. All distributions of osteoarthritis (OA) and abnormal bone formation (ABF) were significantly right-skewed, indicating that the majority of sampled individuals demonstrated a low number of insults. Kruskal-Wallis tests showed significant differences in three comparisons when all 85 individuals were examined:

- MWF showed significantly more bones affected by osteoarthritis than LWF (Wilcoxon $\chi^2 = 7.91159$; $df = 1$; $p = .0049$).
- MWM showed significantly more bones affected by osteoarthritis than LWM (Wilcoxon $\chi^2 = 4.5495$; $df = 1$; $p = .0329$).
- The total Middle Woodland sample showed significantly more bones affected by osteoarthritis than the total Late Woodland sample (Wilcoxon $\chi^2 = 11.3524$; $df = 1$; $p = .0008$).

A correlation run on the z-score residuals of OA and ABF showed a slight positive relationship (Pearson's $r = .2021$; $df = 83$; $t = 1.880$) between the two insults. However, the coefficient of determination suggests that changes in osteoarthritis explained only 4 percent of the changes in abnormal bone formation, and a two-tailed t-test demonstrated that these results were not significant at the .05 level.

Results: Category 2—Dental and Alveolar Insults

When the sample distributions of Category II insults were tested for normality, 19 of 24 (79 percent) were found to be right-skewed, indicating that the majority of sampled individuals suffered from a low number of insults. Of all Kruskal-Wallis tests performed on dental and alveolar insults, only three were significant.

- LWF showed significantly higher z-score residuals for hypoplasias than MWF (Wilcoxon $\chi^2 = 3.9116$; $df = 1$; $p = .0480$).
- The total Late Woodland sample showed significantly higher z-score residuals for hypoplasias than the total Middle Woodland sample (Wilcoxon $\chi^2 = 7.7979$; $df = 1$; $p = .0052$).
- The total Middle Woodland sample showed significantly higher z-score residuals for alveolar resorption than the total Late Woodland sample (Wilcoxon $\chi^2 = 5.8736$; $df = 1$; $p = .0154$).

T-statistics were used to test the significance of the correlation between the z-score residuals of dental insults (hypoplasias and caries) and the correlation between the z-score residuals of alveolar insults (resorption and abscesses). Neither the relationship between dental insults (Pearson's $r = .0033$; $df = 83$; $t = .0301$) nor the relationship between alveolar insults (Pearson's $r = -.0015$; $df = 83$; $t = .0137$) was significant at the .05 level.

Discussion

The majority of the suite of skeletal health indicators examined occurred at very low frequencies or did not differ significantly between sample groups. While the small sample size used in this pilot study limits substantive conclusions, three

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Table 4. Average Z-Score Residuals for Hypoplasias and Abscesses.

Sample	MWF	LWF	MW Total	LW Total
Average Residual of Z-Score for Hypoplasias	-0.2108	0.3660	-0.2846	0.2916
Average Residual of Z-Score for Abscesses	-	-	0.1892	-0.1851

Note: Averages shown are only for groups found to differ significantly from one another.

health indicators showed significant differences between sex or time period, illustrating the potential utility of the z-score method. First, the significant difference in hypoplasias between the Middle and Late Woodland periods, with individuals in the Late Woodland demonstrating more hypoplasias than expected given their degree of dental completion (Table 4), suggests a heightened degree of early nutritional stress in the Late Woodland, a finding that agrees with previous studies (Cook 1979). Second, the Middle Woodland sample showed higher levels of resorption than predicted given the number of preserved tooth sockets. This result runs counter to initial expectations given the documented relationship between soft carbohydrate foods and increased alveolar resorption in agricultural societies (Cohen and Armelagos 1984), but Goodman and Martin (2002) provide evidence that dental attrition rates can be higher in some hunter-gatherer populations, leading to higher rates of premortem tooth loss in these groups. Third, LWF demonstrated greater numbers of hypoplasias than expected given their degree of dental completion, in contrast to the LWM sample, which showed no significant difference from its Middle Woodland counterpart. These results should serve to stimulate further research on the etiology of pre-mortem tooth loss and the relationship between childhood and adult health in the lower Illinois River Valley during the Woodland period.

Conclusions

The significant relationships between skeletal or dental preservation and insult frequency observed in this study suggest that bioarchaeologists must be cognizant of the effects of the completeness of remains on the observability of health indicators. Additionally, the nature of such relationships must be established before drawing rigorous conclusions about individual health and disease in prehistoric samples. However, rather than limiting data collection to well-preserved individuals—a feat that may be impossible for studies of prehistoric health, where samples are often small at the outset—this study offers a method of establishing the quantitative relationship between particular insults and skeletal or dental preservation within a given sample and examining the relationships between different health indicators made commensurate through z-score transformations.

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Data Availability Statement. The human skeletal remains used in this analysis are from the sites of Carter, Gibson, Ledders, and Helton. These individuals are currently curated at the Center for American Archeology in Kampsville, Illinois.

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Notes

1. Data on skeletal completion and health indicators for 85 individuals were collected in July 2011 and October 2012 by two different observers. Jess Beck collected data from the Carter, Ledders, and Ray populations (n = 55), and Kyle Waller collected data for Helton and the majority of the Gibson site (n = 30). Initial data was collected jointly to ensure replicability of results, and the same scoring system and observational criteria were employed by both observers.

2. The regression of abnormal bone formation counts against skeletal completion showed no significant relationship (R^2 = .04215, p = .0594) but the regression of osteoarthritis counts against skeletal completion showed positive and significant results (R^2 = .095565, p = .0040). Because the p-value for the ABF test was close to .05, while the p-value for the OA test was significant, it was necessary to control for differences in skeletal completion before testing for differences between period-sex and period subsamples.

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