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PAPER

ANTHROPOLOGY

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The Effects of Body Mass on Cremation Weight*

ABSTRACT: Cremains have become increasingly frequent in forensic contexts, while higher body mass in the general population has simultaneously made cremation a more cost-effective mortuary practice. This study analyzed the relationship between body mass and bone mass, as reflected through cremation weight. Antemortem data were recorded for samples used in the multi-regional data set. Each was rendered through commercial crematoriums and reweighed postincineration. Pearson's correlation demonstrates clear association between body mass and cremation weight ($r = 0.56$; $p < 0.0001$). However, multiple linear regression revealed sex and age variables also have a significant relationship ($t = 7.198$; $t = -2.5$, respectively). Regressed in conjunction, body mass, sex, and age contribute approximately 67% of all variation observed in cremation weight ($r = 0.668$). Analysis of covariance indicates significant regional variation in body and cremation weight. Explanations include bone modification resulting from increased loading stress, as well as glucose intolerance and altered metabolic pathways related to obesity.

KEYWORDS: forensic science, forensic anthropology, cremains, bone mass, body mass index, obesity

Burned bone has long been a subject of interest for anthropologists in various contexts (1–5). Forensic anthropologists are often requested to analyze a set of burned remains when questions are raised concerning the identity or manner of death (6–8). Commercial cremation presents a unique situation whereby bone is first incinerated and then mechanically reduced into particles comparable to sand or silt. The few remaining fragments are intentionally rendered so small that many diagnostic features are lost (9). For this reason, cremations are usually relegated to forensic anthropologists with expertise identifying burned, charred, deformed, or fragmentary bone.

Cremation is now considered a conventional option in the funerary industry. Reasons for this trend are multifaceted: a number of religious faiths have renounced sanction against burning human remains, declining popularity of more traditional burial options, and greater availability of commercial crematoriums. Economic advantage seems to be a primary factor. The commercial cremation process requires fewer goods and service and virtually no associated long-term maintenance (10,11). For surviving kin who bear the financial burden, cremation may be the most cost-effective and sometimes singular option.

Cremation has also become more frequent in forensic contexts, the most notable case being that of dubious practice by the Tri-State Crematorium (Noble, Georgia) in 2001 (12). Forensic literature reflects this trend. Cremated remains, or cremains, have received greater attention than in any prior decade. For a more comprehensive review of research and analysis on burned human remains, see Fairgrieve (9) and Schmidt and Symes (13). One of the more recent areas of cremains research employs chemical techniques on the residual inorganic compounds. Trace elemental analysis of inorganic materials has been used to differentiate cremated remains from other nonhuman material. Warren et al. (14) used particle-induced X-ray emission to evaluate and refute the legitimacy of a set of cremains. Brooks et al. (15) also used inductively coupled plasma-optical emission spectroscopy to successfully discriminate elemental components in cement, plaster, and other substances often used to mimic cremations. Although informative, these biophysical and chemical techniques require access to expensive equipment, trained technicians, and a sufficient amount of material for destructive analysis. Such requisites present a major impediment to many laboratories and medical examiners' offices that may be called upon in cases involving cremations.

A small number of studies have investigated the physical properties of cremated human remains. The primary anthropometric study by Warren and Maples (16) initially established that cremations are almost entirely derived from longbones of the skeleton. Preliminary work by McKinley (17) reported differences in the amount of cremains produced by men and women and different quantities produced at various ages at death. Bass and Jantz (12) further determined sexual dimorphism in cremated remains; that male cremains are consistently heavier than that of females. The authors also suggested that differences may exist between samples from different geographic regions. This study attempts to increase the body of knowledge about the physical properties of cremains. In the absence of biochemical technology for more complex analysis, what can researchers say about a set of cremains?

Concurrent with these mortuary trends, the modern American population has experienced immense secular change in both height and weight (18–20). The funerary industry has struggled to provide products reflective of these alterations in shape and size. Average body dimensions of modern deceased individuals far exceed measurements in previous decades, from which mortuary equipment standards were created. Currently, many modern funeral homes

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receive individuals who surpass the largest standard size in mortuary apparatus (such as caskets, burial plots, and hearses). This has required a large-scale product transformation by suppliers in the industry: a cost that is often passed down to the consumer (21). This is yet another reason why cremation has been preferentially selected in recent decades.

The long-term consequences of higher body mass and adiposity are severe and systemic, particularly levels classified as clinically obese (19,20,22). This extraneous weight has irrevocable effects on the skeleton (23). Obesity has been linked with several biological and osteological conditions, including diabetes, hypertension, high bone mineral density, osteoarthritis, and DISH (24–26). It is hypothesized that greater antemortem body mass effectively produces more skeletal material, evidenced through the amount of cremains produced after death.

This study offers the largest multi-regional sample size of modern cremains ever combined, representing both sexes and a wide age distribution. This research proposes to analyze the correlation between cremation weight and body mass, as well as body mass index (BMI). Influential demographic factors (sex and age) were further investigated for potential covariation. An attempt to discern whether significant variation exists between geographic subsamples, which could guide investigators working within different regions or with a set of unidentified cremains, was also undertaken.

Materials and Methods

To obtain a significantly large sample size, data were combined from four separate collections of cremations, sourced throughout the United States. This includes Warren and Maples (16) anthropometry research derived from Central Florida (WM); the William M. Bass Skeletal Collection of Knoxville, Tennessee (UTK); the University of Tennessee-Chattanooga Donated Collection (UTC); and cremations produced by the Newton-Bracewell Chico Funeral Home, of Chico California (NBCFH) (27). All samples were rendered through the modern cremation process from a variety of crematoria. Consequently, each collection shows broad variation in quality and appearance. (see Fig. 1*a–d*). Total sample size contains 761 cremations, consisting of 412 male and 349 female samples (see Table 1).

Samples from the UTK were analyzed by the author. UTK samples are housed in a box measuring $42.5 \times 19.4 \times 15.8$ cm. Depending on the entry date into the collection, most cremations are held within a sealed bag and then placed in the box. However, the earliest cremations directly interface with the interior of the box. Each cremation sample in the collection was weighed using a CPW plus-35 scale (kg; Adam Equipment Co Ltd, Danbury CT) subtracting the weight of containing vessels. Procedure was performed twice to reduce human error. Data from additional collections (WM, UTC, and NBCFH) were obtained using a similar procedure and provided by the original researcher or curator of these collections. Age, stature, perimortem weight, and any additional information were recorded whenever available.

BMI was calculated in each case with sufficient perimortem data available. Within the medical and health disciplines, BMI is considered a more accurate indicator of true body composition, incorporating two dimensions both height and weight. BMI is calculated as weight divided by height squared: kg/m^2. Under these guidelines, several levels of body size are described (levels are equivalent for both men and women). A BMI statistic ranging from 18.5 to 24.99 is considered "normal," while anything below is labeled underweight. Overweight is defined as 25.00–29.99, and 30.00 marks the threshold for obesity (28,29). Samples calculated as "obese" were noted during the study. Although BMI was utilized in the present study, several limitations related to its use exist. This includes the inability for BMI to differentiate between standing versus sitting height or to distinguish the contribution of fat versus muscle in total-body mass

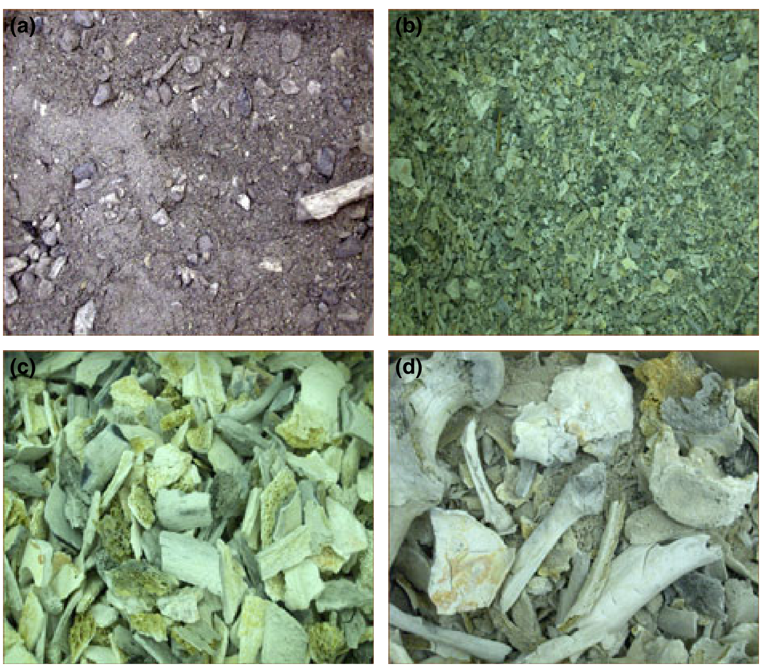

FIG. 1—*Variation in quality of cremains from the William M. Bass donated skeletal collection. (a) Bone ash: material comparable to sand or silt, particles <1 mm. (b) Bone pulverized: particles 1–10 mm. (c) Fragmentary bone: particles 10–20 mm. (d) Incinerated only: bone unpulverized, large particles with identifiable diagnostic features.*

TABLE 1—*Total tested sample, including number, sex, and original collection.*

Collection	Male	Female	Total
UTK	7	4	11
UTC	10	4	14
WM	46	35	81
NBCFH	349	306	655
Total	412	349	761

(30–32). These caveats should be considered when reporting and comparing BMI results.

The relationship between cremation weight and body mass and between then cremation weight and BMI was analyzed using simple and multiple linear regression. Regional variation between sample collections was investigated through a general linear model analysis of covariance (GLM-ANCOVA). All comparisons and statistical analyses were conducted using SAS 9.3.1 and NCSS 3.0 statistical software packages (33,34).

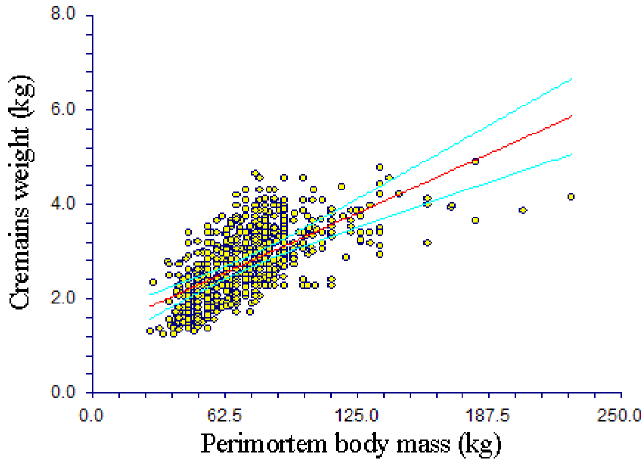

FIG. 2—*Linear regression of cremation weight (kg) on perimortem body mass (kg) for total sample (including 95% upper and lower confidence limits). ○ Plot of individual cremation weights against body mass.*

Results

The mean and standard deviation was derived and compared between the collections (see Table 2). Student's two-sample *t*-test detected significant differences between male and female cremation weight ($p < 0.05$); therefore, sexes were analyzed both separately and pooled in the following tests. Because of lack of perimortem data (cadaver stature), one of the data sets (NBCFH) could not be included in analyses using BMI. Tests using BMI as a proxy variable for living weight have a reduced sample size, which should be taken into consideration when comparing BMI versus body mass results.

Correlation Between Cremation Weight, Body Mass, and BMI

Pearson's correlation coefficient yielded a positive association between cremation weight and both measures of body weight. Body mass produced a slightly higher correlation with sexes pooled ($r = 0.657$, $R^2 = 0.431$, $p < 0.001$) and sexes separated (male $r = 0.595$, female $r = 0.661$). A lower positive association was also shown between calculated BMI and cremation weight, with sexes pooled ($r = 0.55$, $R^2 = 0.31$, $p < 0.001$) and when separated (male $r = 0.544$, female $r = 0.630$). In both cases (using body mass or cremation), female values demonstrated slightly stronger correlation (see Figs 2 and 3).

Multiple Linear Regression of Cremation Weight Against Sex, Age, and Body Mass/BMI

Multiple linear regression was conducted to assess the potential affects of several influential variables. Table 3 displays statistical results from two models: (i) body mass, sex, and age regressed on cremation weight; and (ii) BMI, sex, and age regressed on cremation weight. The sex variable was numerically coded with males denoted as "1" and females assigned "0." Both models were significantly associated with cremation weight (model 1: $p < 0.001$, $R^2 = 0.6229$; and model 2: $p < 0.001$, $R^2 = 0.6117$). In both models, sex and the body weight proxy variables were positively related to cremation weight, although sex demonstrates a closer relationship in the case utilizing BMI (sex $t = 8.066$ vs. BMI: $t = 6.023$). Age had a negative relationship with cremation weight in both tests ($t = -16.36$, $t = -2.494$): an expected result given documented progressive reduction in bone density with advancing age.

Regional Variation: GLM-ANCOVA

A GLM-ANCOVA was constructed to investigate possible differences between regions, using cremation weight and sex as main effects and body mass as a potential covariate. Samples were coded according to geographic origin. Samples from UTK and UTC were given the same code as there is significant overlap in their regional distribution. The ANCOVA revealed significance for both main effects and body mass as a covariate. Controlling for body mass, no interaction was shown between sex and region, indicating that while cremation weight varies between regions, but is not dependent upon sex. Furthermore, there is discrepancy between the sexes, but this diversity is consistent throughout all three regions.

Tukey's post hoc tests and pair-wise comparisons indicate that greatest variance originates from Region 2 (WM sample, Florida); this collection shows significant difference from the other two collections. No significant discrepancy could be found between Region

TABLE 2—*Regional variation in mean weight (kg) of cremains.*

		Males			Females		
Region	Geographic Location	*N*	Mean	SD*	*N*	Mean	SD*
Region 1 (UTK and UTC combined)	Tennessee	17	3.10	0.6542	8	2.36	0.2235
Region 2 (WM)	Gainesville, Florida	46	2.775	0.4992	35	1.858	0.5344
Region 3 (NBCFH)	Northern California	349	3.24	0.5809	306	2.28	0.4819
Bass–Jantz†	East Tennessee	151	3.379	0.6349	155	2.35	0.5364

*Standard deviation.
†Data from the Bass–Jantz (2004) research was not included in the particular study. See (12).

TABLE 3—*Multiple linear regression: cremains weight regressed on sex, age, and BMI or body mass.*

Effect	df	Mean	Standard Error	*t*-value	Pr > F	*R*-square
Body mass (n = 761)						
Model	3	–	0.213 (MSE)	–	<0.0001	0.6229
Sex	1	0.55	0.0366	17.91	<0.0001	
Body mass	1	71.5 kg	0.0008	18.55	<0.0001	
Age	1	72 years	0.0011	−5.59	0.0035	
BMI (n = 106)						
Model	3	–	0.203 (MSE)	–	<0.0001	0.6117
Sex	1	0.60	0.0968	8.066	<0.0001	
BMI	1	24.7 kg/m^2	0.0055	6.023	<0.0001	
Age	1	67 years	0.0032	−2.494	0.0159	

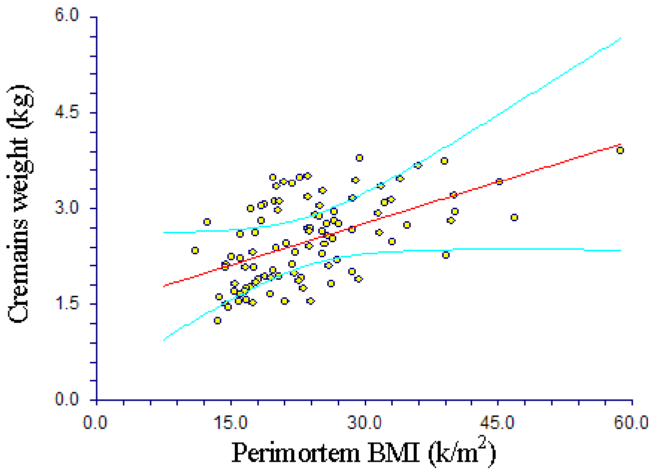

FIG. 3—*Linear regression of cremation weight (kg) on perimortem BMI (kg/m2) for total sample (including 95% upper and lower confidence limits). ○ Plot of individual cremation weights against BMI.*

1 (combined UTK and UTC) and Region 3 (NBCFH) (see Figs 4 and 5).

Discussion

A significant positive correlation was demonstrated between cremation weight and measures of perimortem body mass. Higher body mass is associated with a number of systemic health consequences. Body mass may become elevated in two types of tissue, fat adiposity and lean muscular mass, although fat mass seems almost entirely responsible for modification in bone density (23). On average, an increase in fat mass by one standard deviation will cause an 8.1% increase in bone density (35). Accumulation of fatty tissues has serious consequences for the body.

Biomechanical methods are typically used to explain the relationship between heightened adiposity and the skeleton. Weight-bearing elements are subjected to greater mechanical stress and must be suitably structured to sustain these loads (36). The most heavily affected areas experiencing the greatest stress are longbones of the lower limbs, articular areas of the knees and ankles, and lumbar vertebrae (37). The cross-sectional cortical area reflects bone's strength to axial compression; a larger area inferring the ability to buffer heavier loads. Likewise, greater strength in a particular orientation (A-P or M-L) suggests that bone robusticity is aligned in a singular direction, perhaps reflecting a specific activity or action.

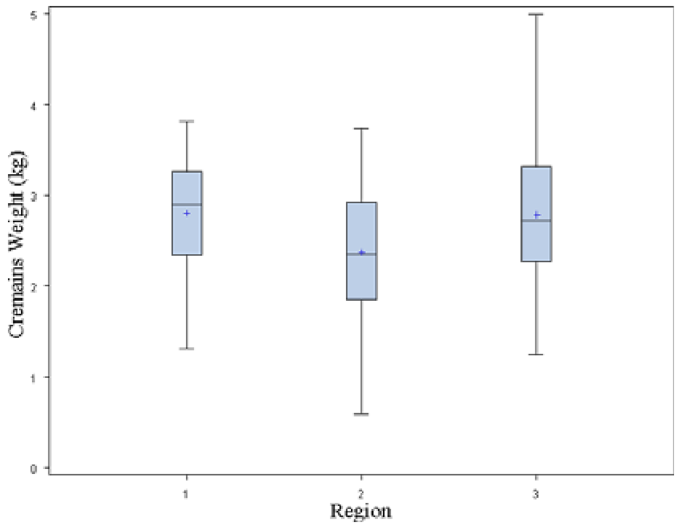

FIG. 4—*ANCOVA results: boxplot of significant difference between geographic regions (sexes pooled). + Regional average cremation weight. Region 1 = Tennessee region (UTK and UTC collections combined). Region 2 = Florida (WM collection). Region 3 = northern California (NBCFH collection).*

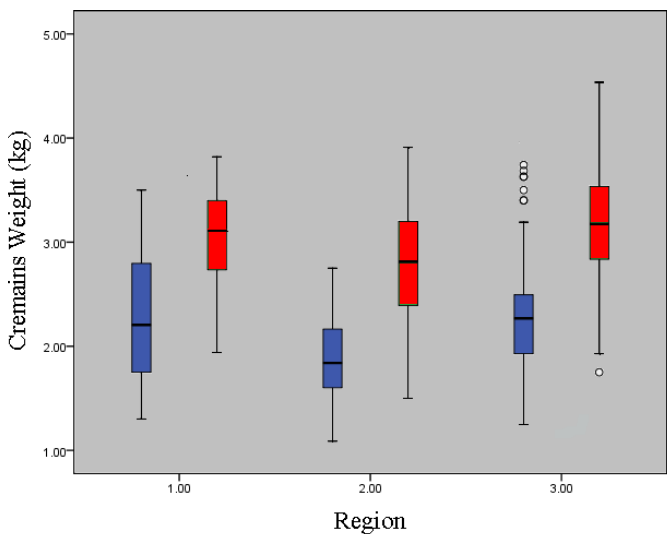

FIG. 5—*ANCOVA results: boxplot of significant difference between geographic regions, by sex. Plot of female average cremation weight ☐ (right box). Plot of male average cremation weight ☐ (left box). Region 1 = Tennessee region (UTK and UTC collections combined). Region 2 = Florida (WM collection). Region 3 = northern California (NBCFH collection). White circles represent individually plotted cremation values.*

Specifically concerning the femur, it has been hypothesized that loading stress would be countered by increased bending strength through elongation in the perpendicular dimension (38).

Numerous studies have looked specifically at bone cross-sectional properties and cortical thickness as a means of estimating body mass. Dalén et al. (39) performed a radiological appraisal of the cross-sectional area of radii and ulna, finding obese subjects had 11% more cortical area on average than the control group. The larger cortices were a result of greater outer diameter, coupled with a slightly smaller inner diameter, suggesting greater apposition and decreased resorption. This translates into an 8% increase in bone mineral content within the radius and ulna (39). Ruff (40) simultaneously found a significant relationship between body weight and measurements of cross-sectional properties, particularly axial strength. Body mass also correlates relatively well with articular areas and bone density (38,41,42). Recently, Moore (37) investigated markers of obesity in the skeleton, finding cortical thickness as observed through computed tomography and dual energy X-ray absorptiometry scans, to be the greatest single indicator of antemortem self-reported weight.

Bone cortical thickness and articular areas are the skeletal areas most heavily modified by body mass and obesity and those that contribute the most cremation mass. It follows that cremation weight may be used to infer perimortem weight, at least in more severe cases of obesity or emaciation. In some forensic contexts involving burning or charring of remains, the most recognizable osteological elements may be destroyed or rendered unidentifiable; cremations may then be used as a proxy. This study presents a new method of understanding body mass and the skeleton, as inferred through the amount of cremations produced.

Furthermore, obesity irrevocably alters the body's metabolism through the production and regulation of several hormones responsible for osteological tissues. At high or even moderate levels, obesity lowers the body's tolerance for glucose (24). Over-nutrition through obesity stimulates the secretion of gastrin hormone, which in turn stimulates the secretion of calcitonin. This hormone effectively inhibits lipolysis in adipose tissues and favors apposition of calcium in bone (43). The metabolic pathway induced by obesity theoretically explains the existence of hyperostosis on vertebrae (39) and "heel spurs" present on calcanei (37). Obesity has also been posited to decrease resorption related to osteoporosis. The altered metabolic process shows a tendency toward increased bone apposition. Even a slight decline in resorption rate could result in a comparatively larger net gain in the percent bone density. Lindsay et al. (44) documented just such an equivocal situation among postmenopausal women.

Recorded weight at death reflects the interrelated factors of body proportions—stature, lean muscle mass, and adiposity—in conjunction with sex and age. When body mass/BMI, age, and sex were collectively regressed, all variables were significantly associated with cremation weight, body mass having the greatest determinate value. While male values were consistently higher than that of females, there was substantial overlap in the distributions. Investigators should be cautioned against using only cremation weight or amount to discern between men and women in unknown circumstances. Women are subject to greater changes in skeletal weight and density, especially with age. This well-documented trend mainly results from the onset of osteoporosis with increasing years. The higher female correlation found in this study is surprising but may result from a greater range of variation in age in the male samples.

In all cases, age showed an expected negative effect on cremation weight, regardless of sex. Lindsay et al. (44) investigated the relationship between bone and body mass in aging women. Using dual-photon absorptiometry, both regional bone mass and total-body bone mineral content (TBBM) were assessed in a sample of premenopausal and postmenopausal women. They recorded postmenopausal women to have lower bone mineral densities in all regions, with a total decrease of 47% over time. For the group as a whole, BMI and percent body fat were strongly correlated with TBBM. For all ages of premenopausal women, body fat was the best predictor of TBBM. With the initiation of menopause, age became the most important factor in calculating TBBM. However, postmenopausal women who were overweight retained a strong correlation between body fat and TBBM (44). In this particular study, the advanced age of many individuals would certainly affect bone mineral content and resulting cremations, potentially obscuring the effects of higher adiposity.

This research also presents evidence of substantial regional variation in cremation weight. Of the three geographic areas analyzed, Tennessee and California were relatively equivalent in average cremation weight, both with sexes pooled and analyzed separately. Significantly lower average values were observed in the central Florida (WM) subsample. Reported levels of body weight and obesity are much lower in the state of Florida (World Health Organization), particularly in comparison to Tennessee, which consistently ranks high as a state with one of the highest rates of obesity, diabetes, and hypertension (29). Furthermore, Florida has a higher median age than either Tennessee or Florida; osteoporosis, osteopenia, and other age-related osteological pathologies probably contributed to the lower average cremains weight noted in the Florida sample. These differences should be taken into account by investigators when determining whether a set of cremated remains falls within an expected or acceptable range. The average cremation weight values published in forensic literature have been primarily derived from the southeastern United States and may not be applicable to other populations with disparate levels of adiposity, biomechanical loading, and glucose-related disorders (12,16).

Calculated BMI shows a similar but slightly lower correlation with cremation weight, an unexpected result considering the additional dimension supposedly incorporated into this measurement. This may be a product of the much smaller sample size with available BMI data. It may be suggested that the effects of age and osteoporosis undermine the ability to effectively measure the BMI. Replacement of muscle tissue with fat during advancing age is coupled with the inconsistency encountered with self-reported height measurements (the method used for the UTK collection). Because many of the cremation samples are elderly, use of BMI as an appropriate measure of adiposity in subjects was a point of contention.

BMI remains the predominant measure employed in health professions and epidemiological studies as an index of body fat, under- and over-nutrition. Proponents of BMI suggest that its validity lies in the way that it diminishes influence of height; in that BMI has maximum correlation with weight and minimal correlation with height (kg/m^2; [45]). Nevertheless, there has been much debate surrounding "what BMI is really measuring" and its use as a predictive indicator of relative "fatness" (30–32). In this particular study, it was not possible to obtain additional data, such as sitting height or skinfold measurements, that might have a closer relationship with true body mass and adiposity. Therefore, it was determined that BMI must be utilized in conjunction with recorded weight at death to better elucidate the relationship between living body mass and the resulting cremations.

Conclusion

Analysis of cremation weight with perimortem body mass and BMI demonstrates a significant correlation among the variables. Increasing BMI levels effectively produces heavier skeletal material, as represented through cremation weight. This may be attributed to skeletal remodeling on weight-bearing bones, induced by increased mechanical and loading stress. Additionally, glucose intolerance and altered metabolic pathways commonly associated with obesity may be responsible for excess calcium apposition in bone. When individually examined by sex, both male and female values proved significantly correlated with their respective cremation weights. Female body mass data had a slightly stronger relationship, probably attributable to the younger average age of women in the sample.

When body mass, age, and sex were collectively regressed, all variables were closely associated with cremation weight. Sex had the highest determinate value, while body mass demonstrated close positive relationship and age showed a close inverse relationship. Regional variation exists between subsamples: cremains from Tennessee and California (including Florida) were significantly heavier than those from central Florida. This study supports previous research documenting the significant effects of heightened body mass, especially obesity, upon skeletal structure. Furthermore, this study has important implications within the field of forensic science. When sex and age can be reasonably proposed for a set of incinerated remains, cremation weight may be a significant aid and source of data for the anthropologist constructing a biological profile.

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References

1. Shipman P, Foster G, Schoeninger M. Burnt bone and teeth: an experimental study of color, morphology, crystal structure and shrinkage. J Archaeol Sci 1984;11:307–25.
2. Buikstra J, Swegle M. Bone modification due to burning: experimental evidence. In: Bonnichsen R, Sorg MH, editors. Bone modification. Orono, ME: University of Maine, 1989;247–58.
3. Nelson R. A microscopic comparison of fresh and burned bone. J Forensic Sci 1992;37(4):1005–60.
4. Correia PM. Fire modification of bone: a review of the literature. In: Haglund WD, Sorg MH, editors. Forensic taphonomy: the postmortem fate of human remains. Boca Raton, FL: CRC, 1997;275–93.
5. Bennett JL. Thermal alteration of buried bone. J Archaeol Sci 1999;26(1):1–8.
6. Bass WM. Is it possible to consume a body completely in a fire? In: Rathbun T, Buikstra J, editors. Human identification: case studies in forensic anthropology. Springfield, IL: Charles C. Thomas, 1984;159–67.
7. Kennedy K. Wrong urn: commingling of cremains in mortuary practices. J Forensic Sci 1996;41(4):689–92.
8. Warren MW, Schultz JJ. Post-cremation taphonomy and artifact preservation. J Forensic Sci 2002;47(3):656–9.
9. Fairgrieve SI. Forensic cremation: recovery and analysis. Boca Raton, FL: CRC, 2008.
10. Cremation Association of North America. http://www.cremationassociation.org/docs/stepbystep.pdf (accessed August 15, 2009).
11. Cremation Association of North America. http://www.cremationassociation.org/html/statistics.html (accessed August 15, 2009).
12. Bass WM, Jantz RL. Cremation weights in East Tennessee. J Forensic Sci 2002;49:1–4.
13. Schmidt CW, Symes SA. The analysis of burned human remains. Boca Raton, FL: CRC, 2008.
14. Warren MW, Falsetti AB, Kravchenko II, Dunnam FE, Van Rinsvelt HA, Maples WR. Elemental analysis of bone: proton-induced X-ray emission testing in forensic cases. Forensic Sci Int 2002;125(1):37–41.
15. Brooks TR, Bodkin TE, Potts GE, Smullen SA. Elemental analysis of human cremains using ICP-OES to classify legitimate and contaminated cremains. J Forensic Sci 2006;51(5):967–73.
16. Warren MW, Maples WR. The anthropometry of contemporary commercial cremation. J Forensic Sci 1997;42(3):417–23.
17. McKinley JI. Bone fragment size and weights of bone from modern British cremations and the implication for the interpretation of archeological cremations. Int J Osteoarch 1993;3:283–7.
18. Meadows LM, Jantz RL. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 1995;40(5):762–7.
19. Flegal KM, Carroll MD, Kuczmarski RJ, Johnson CL. Overweight and obesity in the United States: prevalence and trends, 1960–1994. Intl J Obes 1998;22(1):39–47.
20. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal K. Prevalence of overweight and obesity in the United States, 1999–2004. JAMA: J Am Med Assoc 2006;295(13):1549–55.
21. St. John W. One size doesn't fit all, so funerals adapt to the obesity trend. International Herald Tribune 2003 Sept 30; Associated Press-AP, http://www.highbeam.com/doc/1P1-83792265.html (accessed August 1, 2009).
22. Heaney RP, Berger-Lux MJ, Davies KM, Ryan RA, Johnson ML, Gong G. Bone dimensional change with age: interactions of genetic, hormonal, and body size variables. Osteoporos Intl 1997;7:426–31.
23. Reid IR. Relationships among body mass, its components and bone. Bone 2002;31(5):547–55.
24. Himes CL. Obesity, diseases, and functional limitation in later life. Demography 2000;37:73–82.
25. Ruff CB, Hayes WC. Bone mineral content in the lower limb: relationship to cross-sectional geometry. J Bone Joint Surg (US) 1984;66(A):1024–31.
26. Jankauskas R. The incidence of diffuse idiopathic skeletal hyperostosis and social status correlations in Lithuanian skeletal materials. Intl J Osteoarchaeol 2003;13:289–93.
27. Van Deest TL. Sifting through the ‘‘ashes'': age and sex estimation based on cremains weight. Proceedings of the 59th Annual Meeting of the American Academy of Forensic Sciences; 2007 Feb 19–24; San Antonio, TX. Colorado Springs, CO: American Academy of Forensic Sciences, 2007;13:378–9.
28. World Health Organization Expert Committee. Physical status: the use and interpretation of anthropometry. Geneva, Switzerland: World Health Organization, WHO Technical Report Series 854, 1995.
29. World Health Organization. Obesity: preventing and managing the global health epidemic. Geneva, Switzerland: World Health Organization Technical Report Series 854, 2000. (Reprinted 2004).
30. Norgan NG. Relative sitting height and the interpretation of the body mass index. Ann Hum Biol 1994;21:79–82.
31. Norgan NG, Jones PRM. The effect of standardizing the body mass index for relative sitting height. Int J Obes 1995;19(3):206–8.
32. Norgan NG. Body proportions and the body mass index during childhood. Am J Hum Biol 1998;10(1):139–40.
33. SAS. SAS statistical applied software. Version 9.3.1. Cary, NC: SAS Institute Inc., 2005.
34. NCSS. NCSS statistical software. Kaysville, UT: NCSS LLC, 2006.
35. Compston JE, Bhambhanti M, Laskey MA, Murphy S, Khaw KT. Body composition and bone mass in post-menopausal women. Clin Endocrinol 1992;37:426–31.
36. Auerbach BM, Ruff CB. Human body mass estimation: a comparison of ‘‘morphometric'' and ‘‘mechanical'' methods. Am J Phys Anthropol 2004;125:331–42.
37. Moore MK. Body mass estimation from the human skeleton [dissertation]. Knoxville (TN): Univ. of Tennessee, 2008.
38. Ruff CB, Scott WW, Liu AY. Articular and diaphyseal remodeling of the proximal femur with changes in body mass in adults. Am J Phys Anthropol 1991;86:397–413.
39. Dalén N, Halberg D, Lamke B. Bone mass in obese subjects. Acta Med Scand 1975;197:353–6.
40. Ruff CB. Body mass prediction from skeletal frame size in elite athletes. Am J Phys Anthropol 2000;13:507–17.
41. Coggon D, Reading I, Croft P, McLaren M, Barrett D, Cooper C. Knee osteoarthritis and obesity. Intl J Obes 2001;25:622–7.
42. Lieberman DE, Devlin MJ, Pearson OM. Articular area responses to mechanical loading: effects of exercise, age, and skeletal location. Am J Phys Anthropol 2001;116(4):266–77.
43. Werner S, Löw H. Inhibitory effects of calcitonin on lypolysis and ^{47}Calcium accumulation in rat adipose tissue *in vivo*. Horm Metab Res 1974;6:30–6.

44. Lindsay R, Cosman F, Herrington BS, Himmelstein S. Bone mass and body composition in normal women. J Bone Miner Res 1992;7:55–63.
45. Ross WD, Crawford SM, Kerr DA, Ward R, Bailey DA, Mirwald RM. Relationship of the body mass index with skinfolds, girths, and bone breadths in Canadian men and women 20–70 years. Am J Phys Anthropol 1988;77:169–73.

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