Body Mass Estimation from Human Skeletal Remains: An Anthropometric Assessment of Nutritional Status in the New York African Burial Ground Population

Julia Oppenheimer
Barnard College of Columbia University
Department of Anthropology
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ABSTRACT

The New York African Burial Ground (NYABG) Project unearthed a population of enslaved and free Africans who lived under severe stress in 18th century Manhattan. Body mass estimation from human skeletal remains offers new insights into the nutritional status of adults and children from the New York African Burial Ground. Anthropometric data from the New York African Burial Ground Project database were used to estimate body mass, stature, and body mass index (BMI) for a skeletal sample of adults (≥18 years, n=110) and subadults (0–17.5 years, n=13). Adult body mass and BMI estimates were assessed relative to the 1960–1962 National Health Examination Survey (NHES) dataset (18–74 years) and the World Health Organization (WHO) international classification of underweight, overweight, and obese. Subadult body mass, stature, and BMI estimates were compared to the 2006 WHO Child Growth Standards and 2007 WHO Growth Reference (0–19 years) and evaluated for stunting (Height ≤ WHO 5%, BMI > -2SD) and wasting (Height > 5%, BMI ≤ -2SD). Mean differences in adult male and female body mass between the NYABG and NHES samples were statistically significant ($p < 0.001$), yet adult male and female BMI estimates fell unanimously within the normal and overweight ranges (18.5–30.0 kg/m^2). Minor sex differences in mean adult BMI estimates were statistically insignificant (p=0.104). Young subadults (0-9 years) showed widespread stunting and wasting compared to the WHO growth charts, indicating both chronic and acute physiological stress. These results suggest that the children of the New York African Burial Ground were disadvantaged nutritionally compared to the adult sample, who sustained high muscle mass in response to strenuous labor. The consideration of biomechanics and body composition in the analysis of human skeletal remains is critically important for assessing nutritional status at the time of death, and serves as a powerful addition to the bioarchaeological toolset.

ACKNOWLEDGEMENTS

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CHAPTER I.
INTRODUCTION

In 1989, the US General Services Administration halted construction of a new federal office building in Lower Manhattan when they encountered the skeletal remains of hundreds of enslaved and free Africans (Blakey 2009). Between 1712 and 1794, the New York African Burial Ground served as a cemetery for enslaved and free Africans (Medford 2009). Initiated in response to a 1697 ban by Trinity Church on churchyard burials of blacks, the African Burial Ground constituted one of the earliest African social institutions in New York City (Medford 2009). Yet, the sacred grounds hardly received the peace and autonomy they deserved. The British transformed the neighboring commons into the first city almshouse, a site for public executions and industrial waste disposal. Medical students frequently desecrated African graves, removing bodies for dissection and experimentation (Blakey 2009; Medford 2009). City officials closed and buried the grounds in 1794. The site and its significance disappeared from historical memory for nearly two centuries.

The unearthing of this history inspired the assembly and activism of many members of the New York African-American community. As Michael Blakey, the scientific director of the subsequent New York African Burial Ground Project recalls, "African-Americans in every walk of life, grandmothers and grandchildren, legislators and inmates expressed a desire to know who these people were, wanting assurance that 'we' have human dignity in death" (2010:61). Beginning in the summer of 1991, excavations funded by the U.S. General Services Administration uncovered several hundred burials within the proposed area of construction (Blakey 2010). Scholars estimate that the site contains approximately 15,000 individuals overall, over 97 percent of whom remain undisturbed beneath the civic center of lower Manhattan (Blakey 2010; Perry *et al.* 2009). In 1993, archaeologists removed the remains of 419 adults and children to the W. Montague Cobb Biological Anthropology Laboratory at Howard University for comprehensive osteological analysis (Blakey 2009). Ten years later, members of the African-American community reinterred their ancestors and memorialized the New York African Burial Ground (NYABG) through ceremonial rites of ancestral return (Blakey 2010).

Scholarly analysis of the massive collection of skeletal data continued after the reburial ceremony that finally laid these remains to rest. Michael Blakey and Lesley Rankin-Hill coedited *The Skeletal Biology of the New York African Burial Ground* (2009), a volume detailing the results of a decade of osteological research. Adhering to the guidelines set out by the *Standards for Data Collection from Human Remains* (Buikstra and Ubelaker 1994), osteological researchers conducted inventories, reconstructed fragmented elements, collected countless metrics, and estimated age-at-death and sex for each individual (Blakey *et al.* 2009b). The investigators used these data to piece together the life histories of enslaved and free Africans living in New York throughout the eighteenth century.

The research team employed interdisciplinary methods to investigate questions of ancestral and residential origin, diet, health, and quality of life. Fatimah Jackson directed genetic sampling and analysis to corroborate craniometric and dental non-metric assessments of African ancestral origin (Jackson *et al.* 2009). Alan Goodman oversaw isotopic analysis of teeth to investigate diet, occupation-related exposure to lead, and residential origin (Goodman *et al.* 2009). Finally, the osteological team conducted a comprehensive analysis of bones and teeth to investigate the manifestation and frequency of disease, musculoskeletal and nutritional stress, arthritis, and trauma, as well as the adverse effects on subadult growth and development (Blakey *et al.* 2009a; Goode-Null *et al.* 2009; Mack *et al.* 2009; Null *et al.* 2009; Wilczak *et al.* 2009).

In the wake of the African Burial Ground Project, historians have greatly enriched a void in the scholarly literature on the lives of enslaved and free Africans living in colonial New York City. As Goodfriend (2008:485) eloquently writes, "Suddenly and dramatically, New York City's African past, figuratively lost for so long, had literally intruded into its present." Blakey and Rankin Hill's (2009) findings have impacted scholarly knowledge on African American colonial history in two important ways. First, these results have exposed a substantial gap in the historical literature of New York City regarding the quality of life for Africans in the pre-Civil War era and at the height of the transatlantic slave trade. The establishment of the African Burial Ground Project and the passionate voices of the African American descendent community prompted a resurgence of scholarly attention to slavery in colonial New York (Goodfriend 2008). Second, where medical records proved inadequate, the study of human skeletal remains provided interdisciplinary evidence to augment this section of the city's past.

As the field of bioarchaeology evolves and new inquiries arise, some ambiguities about the health and quality of life of New York Africans in the 18th century remain unanswered. Following an increased focus on the plasticity of human growth, development, and tissue maintenance in response to biocultural stressors (Kuzawa 2007; Ruff *et al.* 2013; Ruff 2008; Saunders 2008; Snodgrass 2012; Stinson *et al.* 2012; Temple and Goodman 2014), this research will estimate body size using structurally relevant dimensions of the femur. The assessment of body mass, body proportions and body composition has wide applications in bioarchaeology, medicine, and public health as an indicator of health and nutritional status (Cole 2012; de Onis *et al.* 2007; Goode-Null 2002; Lejarraga 2012; Norgan *et al.* 2012; Ruff *et al.* 2013; Tanner 1981). This thesis endeavors to provide supporting evidence for preliminary findings of growth deficits within the New York African Burial Ground population (Goode-Null 2002; Goode-Null *et al.*

2009), and to enrich an interpretation of nutritional status in adults and subadults using novel anthropometric indicators of body mass and body mass index (BMI).

Chapter II provides a historical overview of the demographics and quality of life of enslaved and free Africans living in Manhattan in the 18th century. The results of analyses conducted as a component of the New York African Burial Ground Project on the paleodemography, osteological indicators of disease, nutrition, and work, and recent and ancestral African origins of this population, provide supporting evidence for this historical narrative. Finally, an investigation of growth and development for the subadult sample of the New York African Burial Ground is summarized. Chapter III engages the literature in human biology on the interpretation of stress from human skeletal remains, on the remarkable plasticity of childhood growth and development and the interpretation of growth and nutritional status from anthropometry, and finally on the principles of bone functional adaptation and biomechanics that underlie the method of body mass estimation.

Chapters III and IV present the samples, methodology, and results for the estimation of body mass and body mass index, and for the comparison of NYABG anthropometric data to modern reference data for nutritional assessment. Chapter V interprets the body size, growth, and nutritional status of subadults and adults from the NYABG, and address the confounding effects of secular trends in body size on comparisons of past and modern populations, the limitations of BMI in assessing nutritional status and body composition, and the assumptions highlighted by *The Osteological Paradox* (Wood *et al.* 1992). Finally, Chapter VI concludes the thesis with a note on the implications of this research not only on the historical narrative of New York Africans in the 18th century, but also on future bioarchaeological research.

CHAPTER II.
LIFE HISTORY OF THE NEW YORK AFRICAN BURIAL GROUND POPULATION

African Slavery in Colonial New York City

Although New York aligned politically with the Union in the events leading to emancipation, the historical narrative often neglects the ubiquity of urban African slavery in the state's center of commerce. Until its abolition by the United States in 19th century, the transatlantic slave trade supplied New York harbors with continual imports of African slaves from Africa and the West Indies (Berlin 2009; Foote 2004). Demand for slaves increased during the eighteenth century as urban citizens found a competitive edge by employing free African labor in a variety of domestic and trade-specific occupations (Clarke 1737). Throughout the journey from Africa, inadequate living conditions and nutrition, exposure to extreme climates, vulnerability to endemic and epidemic disease, and severe demands for labor systematically weakened the health and fertility of slaves prior to and long after their arrival in New York (Medford 2009). Moreover, public sanctions against the breeding of slaves resulted in increased reliance on imported slaves from Africa, which jeopardized the health and continuity of an African population in New York (Berlin 2009). This chapter weaves bioanthropological evidence from the African Burial Ground together with the historical record to provide an overview of the health, demographics, and life histories of African slaves in New York City throughout the eighteenth century.

Conditions of the Transatlantic Slave Trade

The high morbidity and mortality of enslaved Africans arriving in New York emerged by virtue of the harrowing transatlantic slave trade. In Africa, enslaved individuals were imprisoned in holding cells while waiting for arrival of the ships, where slaveholders denied them adequate space, ventilation, and nutrition (Medford 2009). Slaves suffered severe illness and malnutrition during the Middle Passage. On the ship, epidemics of smallpox, fever and dysentery ran rampant (Medford 2009). For those who survived, quality of life hardly improved during temporary employment on sugar plantations in the West Indies. The African slaves faced stark changes in climate and seasonality, with no reprieve from extreme labor. William Winterbotham (1796:134) writes from the Spanish province of Grenada in 1796 that African slaves were employed to mine in the open air for shallow gold deposits because “the chill subterranean air has been discovered, by experience, to be so fatal to them, that they cannot be employed with advantage in the deep silver mines.”

African slave populations were especially vulnerable to abrupt changes in weather accompanying the transitions between seasons. Dr. William Hillary (1766) documents disproportionate morbidity of African laborers during the cold, rainy season in Barbados. Hillary reasons that the abrupt change in climate and reduction in sweating upset the balance of bodily “humours.” Food shortages and consumption of unripe produce during these seasons likely led to digestive illnesses and malnutrition. For Hillary (1766:26), the “Herbs, Roots and Fruits” which comprised much of their diet turned “crude and waterish” during the rainy season, lacking nutrition or rotting. In his published letters home to London in 1789, William Dickson, a former secretary to the then governor of Barbados, also provides evidence of seasonal famine and malnutrition. Dickson (1789:7) writes:

> "The field negroes divide their year into the *crop-time* and the *hard time*. During the former, though they labour almost incessantly, the nutritious effects of . . . the sugar cane, are very visible on them. But, should the dry weather continue long, after the crop is over, as is often the case, the poor creatures, having then nothing but their bare allowance to subsist on soon begin to prove, by their famished looks, the total insufficiency of that allowance for their support. Before the end of the drought, they are often quite emaciated."

Dickson (1789:7) notes that without reliable access to nutritious crops, African slaves had no choice but to "devour the crude fruits . . . which co-operate with change of weather, bad lodging, and other causes, in inducing fluxes, and a disease resembling the dropsy." By Hillary's account, the African laborers were insufficiently fed, poorly clothed, and, as such, ill-prepared to labor in inclement weather.

Throughout the West Indies, endemic diseases threatened populations made vulnerable by extreme labor and poor living conditions. Hillary (1766:26) explicitly notes that "the Negro Slaves are generally the first seized with such Diseases as are epidemical or endemial in this Island." In a collection of letters, Mr. John Quier wrote to Dr. D. Monro in London regarding the spread and treatment of small pox among new African arrivals in Jamaica. Although small pox had long been endemic to this region, the disease ravaged slave populations in epidemic proportions. Quier also noted cases of yaws among children, and venereal diseases being passed from mother to child during breastfeeding (Elliot *et al.* 1778).

The writings of British colonial officials and physicians suggest that malnutrition and epidemics of venereal and other infectious diseases threatened birth rates and infant survival in the West Indies (Dickson 1789; Elliot *et al.* 1778; Hillary *et al.* 1766; Winterbotham 1796). Yet, conditions in New York City were no more hospitable to growth and continuity of the African slave population (Berlin 2009; Foote 2004; Freeman 1994; Harris 2003; Medford 2009). Deliberate constraints on African fertility in New York resulted in a self-reinforcing demand for the import of new African slaves throughout the 18th century (Clarke 1737; Davis 1984). Enslaved Africans arrived at the New York City trade port in debilitating condition, their bodies already ravaged by illness, poor nutrition, and extreme labor (Medford 2009). As such, the transatlantic slave trade severely disadvantaged the health and vitality of New York Africans from the moment of their arrival, and its perpetuation throughout the era of slavery made this affliction impossible to overcome.

The Origins of New York African Slaves

The origins of the population interred at the African Burial Ground was a central research interest for Goodman and other members of the osteological team. Goodman *et al.* (2009) aimed to elucidate whether individuals were victims of the transatlantic slave trade or born to enslaved or free families in New York. Isotope analysis of rubidium, strontium, lead, cerium, and lanthanium clustered individuals by African birth and non-African birth (Goodman *et al.* 2009). These data revealed a significant African-born majority among adults, and, for some, temporary residence in the Caribbean. Furthermore, Goodman *et al.* (2009) found support for their hypothesis that adults with cultural dental modifications, including filed, notched, and extracted teeth, spent their childhood in Africa. Young children with unmodified teeth, on the other hand, had isotopic signatures consistent with birth in New York. Dental isotope analyses from the African Burial Ground therefore suggest that between 1712 and 1794, a significant majority of mature slave laborers who lived and perished in New York were born in Africa or the Caribbean.

In contrast with that of the rural south, urban New York slaveowning culture discouraged slaves from building families and producing healthy, American-born generations unaffected by the trials of the Middle Passage (Berlin 2009; Davis 1984). In April, 1737, Lieutenant-Governor George Clarke of New York responded to grievances among tradespeople in the city regarding the unfair advantage afforded to some by the free labor of slaves. “The artificers complain with too much reason of the pernicious custom of breeding slaves to trades, whereby the honest and industrious tradesmen are reduced to poverty for want of employ, and many of them forced to leave us to seek their living in other countries” (Clarke 1737:258). Many craftspeople and business owners did not own slaves, and as such, those who could afford slaves and produce generations of free laborers born into the industry wielded a significant advantage.

Whether to avoid ridicule from competitors in industry, or to prevent the disadvantage of pregnancy and childcare on productivity, New York slaveholders took measures to prevent reproduction among African slaves throughout the latter half of the eighteenth century. Males were held in separate households from females, and were forcefully prevented from visiting their wives. Female slaves who became pregnant received fervent hostility for the inconvenience of less available labor (Davis 1984).

The discouragement of family building among New York African slaves, which led to the continued import of slaves throughout the 18th century, perpetuated the disastrous effects of the transatlantic slave trade on slave health. The constant influx of slaves from Africa via the West Indies—and high mortality of those who had already arrived—contributed to an ever increasing majority of African or Caribbean born individuals in New York City between 1703 and 1777 (Foote 2004:69). Even the American hero Benjamin Franklin recognized the need for “a continual supply … from Africa” to maintain the labor force provided by African slavery (Cited in Berlin 2009:186). Figure 1 illustrates the distribution and origin of African slaves imported to New York City throughout most of the eighteenth century, with data compiled from multiple sources (Carter *et al.* 2006; Medford 2009) . These records show continuous replenishing of slaves by the transatlantic slave trade from both the West Indies and Africa throughout much of the period of use of the African Burial Ground.

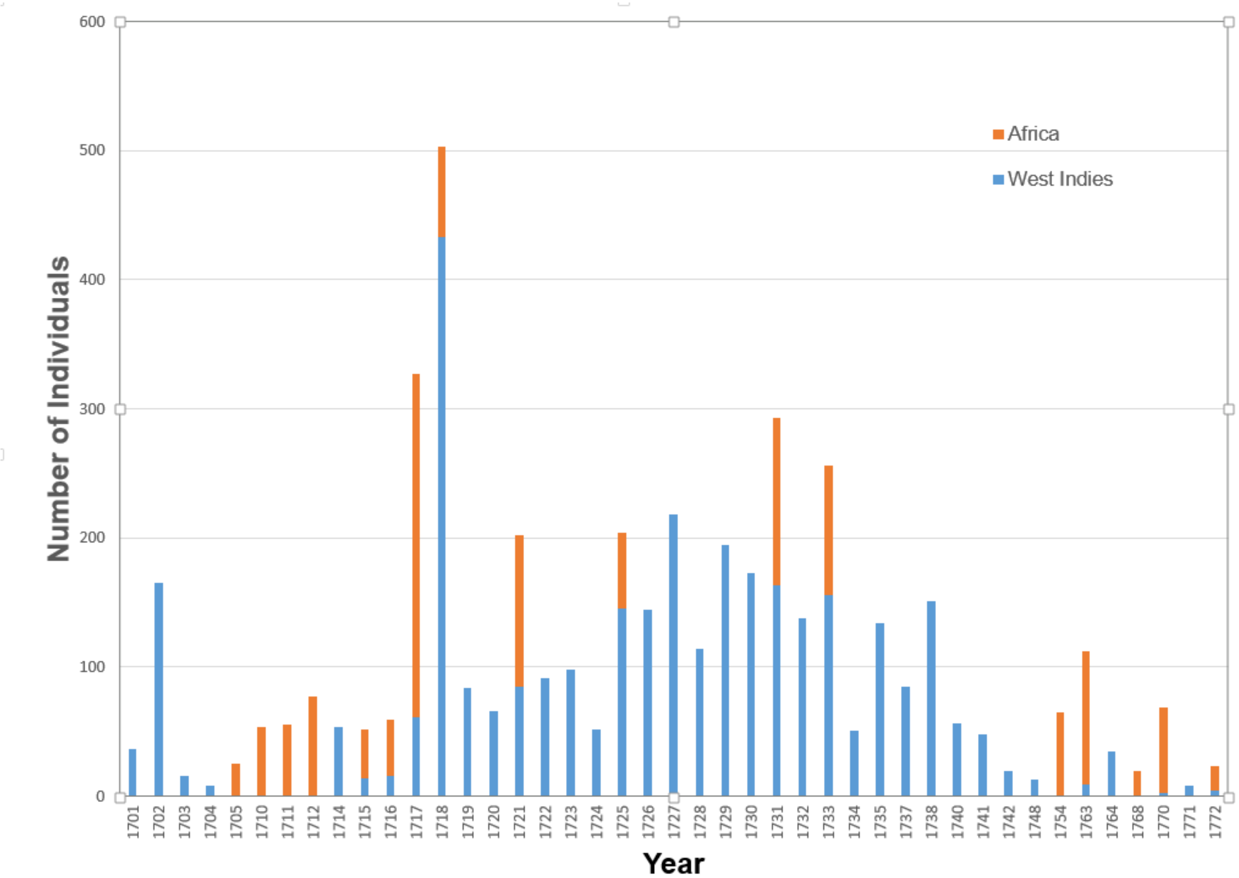

Fig. 1. Number of African slaves imported to New York City by country of origin, 1712–1772 (compiled from Carter *et al.* 2006; Medford 2009).

Health and Labor of New York Africans

Each group of new arrivals faced the same bleak prospects for thriving in the New World. The masses of African men and women arriving in New York City were ill-adapted to the climate and contagions of the new environment and suffered illness and fatalities (Foote 2004; Freeman 1994; Harris 2003; Medford 2009). Despite the duration of several months following a July or August arrival to acclimate to a colder climate, bitter New York winters took an extreme toll (Foote 2004). Poor nutrition, insufficient clothing, severe labor, and inadequate living conditions exacerbated poor health and increased the risk of morbidity (Foote 2004; Medford 2009). Slaves survived on corn and cereal grains, including a porridge made from ground corn, as well as beef broth and bread (Medford 2009). Food and rum storage in pewter containers often caused lead poisoning (Medford 2009).

Throughout the city, slaveholders and landlords relegated slaves and free blacks to dank, poorly ventilated cellars where they were exposed to disease. Likened to "Dens of Death," cellars would collect filthy water, exposing their tenants firsthand to water born epidemics (Freeman 1994:167). Epidemics of yellow fever and smallpox in 1702 and 1756, respectively, ravaged populations of new African arrivals (Foote 2004). The Bancker Street yellow fever epidemic in 1805 provides a salient example of the drastic difference in susceptibility to disease between upstairs and downstairs residences. During this epidemic, 33 out of 48 individuals of African ancestry living in ten cellars on Bancker Street became sick, and nearly half died, yet not a single one of 120 European Americans living upstairs became ill (Harris 2003:79). The threat of measles, whooping cough and other highly contagious diseases dissipated following childhood in populations of European ancestry, but devastated African adults (Berlin 2009). Moreover, medical treatments for all demographic groups at the time, which included bloodletting, emetics, laxatives, and sweating, "likely traumatized the body as much as the disease" (Medford 2009:84).

The overall findings of Blakey and Rankin-Hill (2009) revealed a population that lived and perished under severe stress. The paleodemographic profile (n=301) showed high mortality among infants, and among adult females and males in their third and fourth decades of life, respectively (Rankin-Hill *et al.* 2009). Rankin-Hill *et al.* (2009) report a low population mean age-at-death of 22.3 years as a result of extremely high infant mortality. The data suggest that less than half of infants survived two years of life (Rankin-Hill *et al.* 2009). Dental enamel hypoplasia frequencies decreased with increasing age-at-death, providing further evidence for poor health and nutrition among New York-born African children younger than fifteen (Blakey *et al.* 2009a). Goodman *et al.* (2009) reported unusually high levels of lead in the developing teeth of first generation African American children, corroborating historical evidence for frequent lead poisoning of slaves. Ubiquitous tooth loss, alveolar resorption, dental caries and abscesses among the African Burial Ground population suggested severe nutritional stress worsened by the inability to chew solid foods (Mack *et al.* 2009). The widespread co-occurrence of skeletal lesions—including periostitis, periosteal reactions to generalized infectious disease, and porotic hyperostosis associated with dietary deficiencies—characterized a population made susceptible to infection by inadequate nutrition (Null *et al.* 2009). Osteologists also reported lower frequencies of medial-lateral long bone bowing, likely due to rickets, hemorrhagic and inflammatory meningeal reactions, osteomyelitis, and various lesions associated with treponemal infection (Null *et al.* 2009).

Results from osteological analysis of skeletal remains from the African Burial Ground also supplement sparse historical data on the labor patterns of enslaved and free New York Africans during the eighteenth century. Benjamin Rush, a prominent physician and civic leader in the colonies, exposed the state of slave health and labor in an anti-slavery pamphlet entitled *An Address to the Inhabitants of the British Settlements in America, upon Slave-Keeping*. Rush (1773:8) writes:

> "I have been informed by good authority, that one European . . . will do twice the work, and live twice the number of years that an ordinary Negro man will do: nor need we be surpriz'd at this, when we hear that such is the natural fertility of soil, and so numerous the spontaneous fruits of the earth in the interior parts of Africa, that the natives live in

> plenty at the expense of little or no labor, which, in warm climates, has ever been found to be incompatible with long life and happiness."

According to Rush, slaveholders were well aware of the poor condition of newly imported African slaves, as well as the adverse effects of cold climate and illness on slave labor and productivity (Rush 1773). Tradesmen and high ranking households were nevertheless enticed to purchase slaves, perhaps reasoning that the continual purchase and exchange of numerous slaves for free labor at low cost would outweigh any losses in efficiency to their poor health (Harris 2003). The demand for labor among urban slaves rivaled that of the West Indies and the rural colonies in severity, and perhaps required a greater degree of versatility and adaptability (Medford 2009).

Although newspaper advertisements objectified the human subjects whom they treated like any other commodity, and often listed slaves for sale in the same sentence, they provide important demographical and occupational information. An example from the *New York Weekly Journal* (1734) reads, "To be Sold, a Young Negro Woman, about 20 Year old, she does all sorts of House work; she can Brew, Bake, boyle roast Soap, Wash, Iron & Starch; and is a good darey Women she can Card and Spin at the great Wheel, Cotton, Lennen and Wollen." This advertisement typifies the diverse and extensive demands of urban domestic work. Slave owners employed their slaves in everything from cooking and cleaning to producing crafts. This would likely have required training, and provided the household a competitive edge in industry and social standing.

While most newspaper articles advertised domestic occupations, others revealed the prevalence of slave employment with merchants in ship yards and on voyages. One such advertisement in the *New York Gazette* (1748) seeks temporary slave labor at sea:

> "For London, the Ship Fliendship, Henry Savage Master; will sail in fourteen Days . . . Any Person that has a Negro Wench that can cook, wash, and iron, and a trusty Negro Boy that is used in Family Work, and is willing to hire them out, may have good Wages for them, and civil Usage."

Households could earn substantial wages for employing their slaves as hired help in trade voyages. The request for laborers skilled in "Family Work" rather than ship maintenance, for example, implies that ship captains expected slaves to adapt quickly to the demands of life at sea.

Slaveholders consistently specified the sex of slaves in their advertisements in accordance with their skills and capacity for labor. The *New York Journal* (1766) advertised, "A Negro Girl Fifteen Years old, used to do sewing, ironing and House Work, to be sold or exchanged for a Negro Lad of 18 or 20, making Allowance for their different Value." Although the individuals proposed for sale or exchange in this advertisement differ slightly in age, the text implies that the sexes were afforded different value, perhaps corresponding to differences in skill sets, strength or productivity. According to Davis (1984:173), slave women carried out domestic tasks, including cooking, cleaning, and other household chores, while slave men proved more valuable for commercial services, as "machines of production in the holders' businesses".

Osteological analysis of the population interred at the African Burial Ground demonstrated the severity of labor among both sexes. Wilczak *et al.* (2009) studied the prevalence of osteoarthritis, spondylolysis, Schmorl's nodes, dislocations, fractures, and over thirty musculoskeletal stress markers in 187 of the African Burial Ground adults. The sites of greatest skeletal hypertrophy and osteoarthritic changes for both males and females were found in the pectoral girdle, vertebral column, and bony insertions of the gluteus maximus and deltoids (Wilczak *et al.* 2009). These stress markers indicated a variety of activities requiring high muscular strain, especially carrying heavy loads (Wilczak *et al.* 2009). The osteologists reported insignificant differences in stress marker prevalence between males and females (Wilczak *et al.*

2009). Therefore, the skeletal remains of this population preserved widespread traces of strenuous and likely debilitating activity during life.

In summary, the combination of grossly inadequate nutrition and living conditions, exposure to unfamiliar climates, endemic and epidemic diseases, together with naturally low fertility, and the systematic prevention of reproduction among African slaves had crippling effects on health and longevity. Urban labor only exacerbated the debilitating physical effects of the Middle Passage and of enslavement in colonial New York City on the health and growth of this population. Many questions regarding the weight-bearing capacity and occupational activity of the individuals interred at the African Burial Ground, however, remain unanswered. New frontiers in human skeletal biology focused on biomechanics and skeletal loading may provide new insights into the labor and growth patterns of this resilient population from centuries past.

Growth and Development in the New York African Burial Ground Population

In both bioarchaeological and clinical assessments, growth and developmental status per subadult age cohort, together with achieved adult stature, provide important information about childhood health and nutrition (Cole 2012; Goode-Null 2002; Goode-Null *et al.* 2009; Goode *et al.* 1993; Lejarraga 2012; Ruff *et al.* 2013). As a component of the New York African Burial Ground Project, skeletal biologists assessed the paleodemography and growth status of the children of the New York African Burial Ground by estimating stature (Goode-Null 2002; Goode-Null *et al.* 2009). Published regression formulas for African American populations (Trotter 1970; Trotter and Gleser 1952) were used to estimate adult stature from diaphyseal length of long bones (Goode-Null 2002; Goode-Null *et al.* 2009). Goode-Null (2002) also constructed sex and age-specific regression formulas for estimating stature from long bone lengths of juvenile skeletal remains based on National Center for Health Statistics (NCHS) statistics for recumbent length (birth to 24 months old) and stature (two to 20 years old). The researchers compared stature estimates from 129 individuals for whom long bone lengths were able to be measured to selected CDC/NCHS growth standard percentiles (Goode-Null *et al.* 2009). Goode-Null (2002) cites a recommendation by the CDC/NCHS that a national growth reference should be used for all ethnic groups, because studies have shown that interethnic variation in growth stems from environmental rather than genetic differences (Kuczmarski *et al.* 2002). The potentially confounding effects of the secular trend on growth in stature and on developmental tempo (Hamill *et al.* 1977; Jantz 1999; Komlos and Breitfelder 2008; van Wieringen 1978), however, are not addressed (Goode-Null 2002; Goode-Null *et al.* 2009)

The results of this assessment demonstrate a disparity in growth deficits between adult males and females of the African Burial Ground population when compared to the CDC growth standards for stature (Goode-Null *et al.* 2009). Figures 2 and 3 show the distribution of individual female and male stature estimates, respectively, relative to the quartile ranges of the CDC/NCHS statistics for normal growth (Goode-Null *et al.* 2009). A majority of adult male individuals from the New York African Burial Ground fall well below the CDC/NCHS 25th percentile for stature (Fig. 2) (Goode-Null *et al.* 2009). Adult female stature estimates, on the other hand, show a majority at or well above the CDC/NCHS 25th percentile for stature (Fig. 3) (Goode-Null *et al.* 2009). Age-specific, indeterminate-sex stature estimates for subadult individuals from the New York African Burial Ground population follow a normal growth curve, but fall almost entirely below the CDC/NCHS 50th percentile (Fig. 4) (Goode-Null *et al.* 2009).

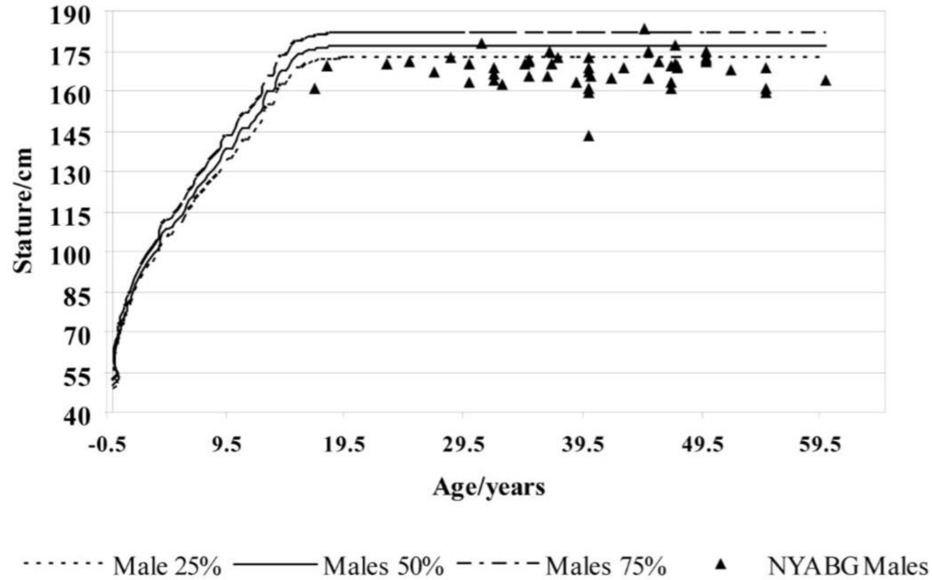

Fig. 2. New York African Burial Ground adult male stature estimates charted against the 1977 National Center for Health Statistics male height-for-age quartiles (modified from Goode-Null *et al.* 2009).

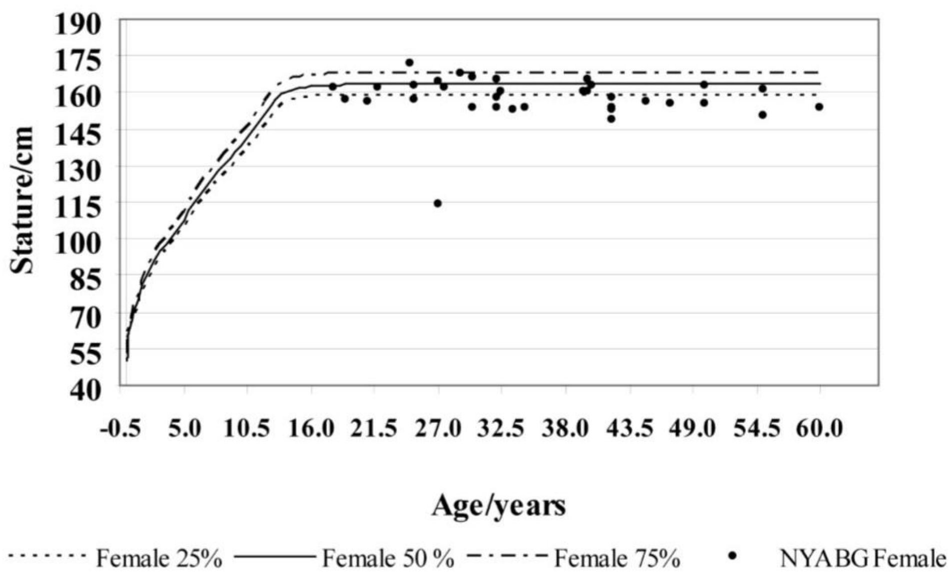

Fig. 3. New York African Burial Ground adult female stature estimates charted against the 1977 National Center for Health Statistics female height-for-age quartiles (modified from Goode-Null *et al.* 2009).

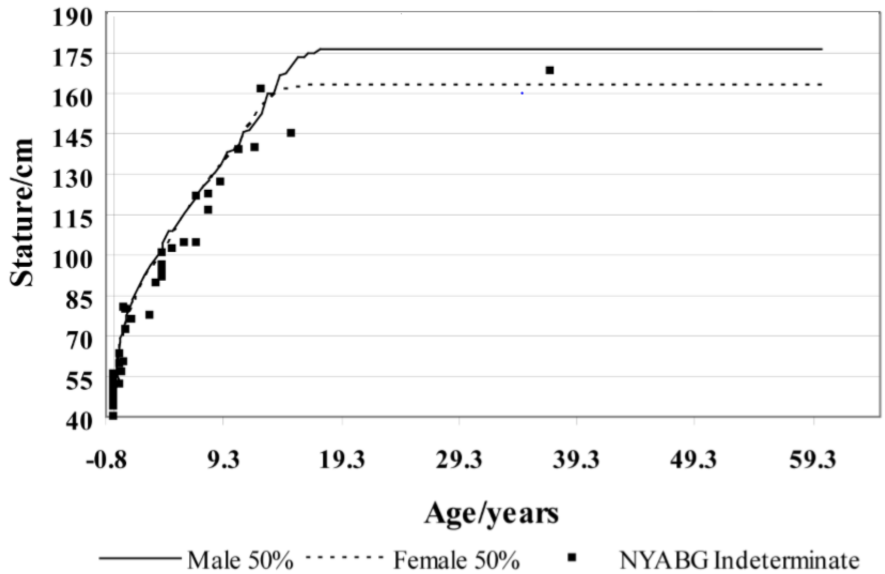

Fig. 4. New York African Burial Ground subadult stature estimates charted against the 1977 National Center for Health Statistics median height per age cohort (modified from Goode-Null *et al*. 2009).

Goode-Null *et al.* (2009) interpreted these results to indicate that this adult female subsample maintained better health than the adult male and subadult subsamples from the New York African Burial Ground population.

To assess the effect of health, labor and nutrition on growth status, Goode-Null *et al.* (2009) correlated stature estimates from the New York African Burial Ground with indicators of nutritional status, including pathologies related to anemias and generalized nonspecific infectious lesions, and biomechanical stress markers (Goode-Null *et al.* 2009). The researchers found no statistically significant relationship between stature percentile ranking and presence or absence of porotic hyperostosis or general infectious lesions (Goode-Null 2002; Goode-Null *et al.* 2009). The associations between stature percentile ranking and biomechanical stress markers were only significant for presence or absence of enthesopathies, or overuse muscle avulsion injuries, in subadults aged six to 16 years (Goode-Null *et al.* 2009).

These results indicate an absence of a significant association between stature estimates and nutritional, disease, and activity-related skeletal indicators of stress (Goode-Null 2002; Goode-Null *et al.* 2009). Nevertheless, the researchers conclude from the ubiquitous stature deficits among the subadult and adult male population subsamples that these individuals must have experienced growth-stunting physiological stress (Goode-Null 2002; Goode-Null *et al.* 2009). This assessment of health and growth in stature for the New York African Burial Ground population will serve as a basis of comparison for the estimated body mass statistics presented in this thesis. The present research will investigate whether body mass and body mass index distributions for adult and subadult samples uphold Goode-Null *et al.*'s (2009) findings that adult males showed greater deficits in achieved body size than females, and that subadults demonstrated widespread growth stunting.

CHAPTER III.
THEORETICAL AND METHODOLOGICAL BACKROUND

The bioarchaeological analysis of population body mass statistics hinges on the plasticity of skeletal tissue in response to the presence or absence of physiological stress. When contextualized with other osteological indicators of nutrition, disease, biomechanics, anthropometrics, and demographics, estimated body mass informs an interpretation of population trends in growth, stress, and baseline robusticity. This chapter surveys the literature in bioarchaeology and human biology and provides a model for the assessment of stress and growth status in skeletal populations.

The Interpretation of Stress from Skeletal Remains

The increased focus over the past several decades on stress as an important aspect for bioarchaeological analysis largely reflects the influences of human biology on the interpretation of life history in past populations (Goodman *et al.* 1984; Ice and James 2012; Temple and Goodman 2014). Stress, as it has come to be defined, depends on a conceptualization of human skeletal remains as once living organisms responding and adapting to conditions of environment and culture (Goodman *et al.* 1984). The "general stress response," presented by the endocrinologist Hans Selye in the 1950s and 1960s, initially specified the heightened activation of the sympathetic nervous system and release of stress hormones from the hypothalamus (Temple and Goodman 2014). Yet, the term "stress" has gained much wider application in in medicine, psychology, and bioarchaeology. Temple and Goodman (2014:186) offer a broad definition for stress, namely a "measurable deviation from a homeostatic resting state." With its initial definition based in endocrinology and its usage applicable in many disciplines related to human health and wellness, stress encompasses diverse physiological and psychological reactions to a variety of environmental and cultural antagonists. Some of these physiological responses leave traces on the skeleton that persist in the archaeological record. Skeletal indicators of stress therefore serve as an imprint of socially and ecologically induced cumulative deviations in homeostasis throughout life (Temple and Goodman 2014). Human skeletal remains provide evidence for the dynamic conditions of lived experience.

This perspective lends itself to a biocultural model of analysis that highlights the interrelatedness of cultural and environmental stressors as well as individual genetic and demographic susceptibility to disease. For Goodman *et al.* (1984:33), stress assessments should consider the “synergistic reaction between infections, poor nutrition, and cultural factors.” The authors divide factors producing physiological stress into three cooperative categories (Fig.). “Environmental constraints” include conditions of limited resources and the introduction of other stressors, such as changes in climate (Goodman *et al.* 1984; Goodman and Armelagos 1989). “Cultural systems” describe the set of social and economic conditions that may buffer or aggravate environmental stressors (Goodman *et al.* 1984; Goodman and Armelagos 1989). Finally, “host resistance” refers to the differential susceptibility of individuals to physiological stressors depending on age, sex, and genetic factors (Goodman *et al.* 1984; Goodman and Armelagos 1989).

The model in Figure 5 shows the relationship between causal factors, skeletal indicators of stress, and population morbidity, mortality, and survivorship. The cumulative effects of environmental, cultural, and host resistance factors result in physiological disturbances that often manifest in living skeletal tissue. Physiological stressors experienced during life may leave traces of “growth disruption” in population-wide measures of stunted stature and long bone

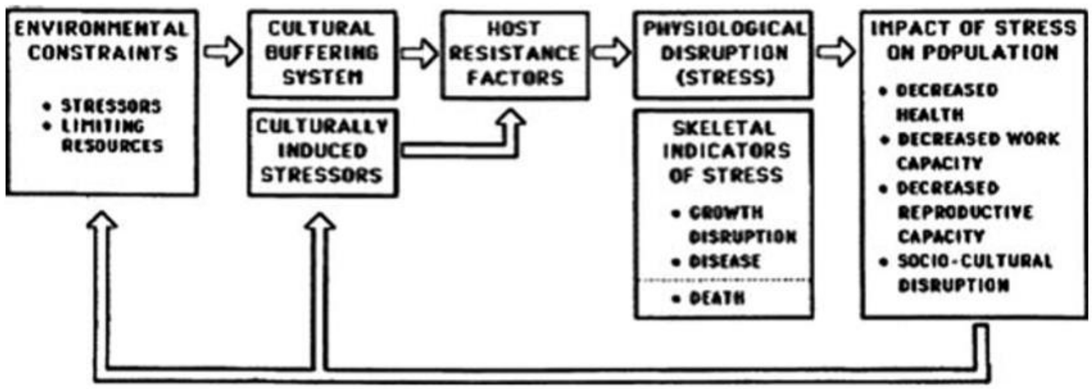

Fig. 5. A biocultural model for the interpretation of stress in skeletal remains from Goodman and Armelagos (1989).

lengths corresponding to nutritional status, or in acute growth defects such as linear enamel hypoplasias (Goodman *et al.* 1984; Goodman 1993). When a fatal disease progresses rapidly throughout a population or population subset, the age-at-death and sex distributions will shift accordingly to reflect patterns of susceptibility (Goodman *et al.* 1984; Goodman 1993; Wood *et al.* 1992). Yet, depending on the severity and duration, disease may leave evidence of morbidity and survivorship by the presence of skeletal lesions (Goodman *et al.* 1984; Goodman 1993; Temple and Goodman 2014; Wood *et al.* 1992). In other words, the presence of skeletal lesions most often represents survival for a long period of time following the disease event.

Skeletal stress indicators inform interpretations of the biocultural impact that the physiological disturbance, or death, may have caused on a population-wide scale. Figure 5 includes within this category "decreased health, decreased work capacity, decreased reproductive capacity, [and] socio-cultural disruption" (Temple and Goodman 2014:188). There is some controversy on the interpretation of health from skeletal remains, yet scholars agree that health is a complex, subjective concept that necessitates assessment of multiple skeletal indicators (Goodman 1993; Temple and Goodman 2014; Wood *et al.* 1992). Physiological perturbation related to nutritional status or disease may lead to poor health, which in turn may have sociocultural ramifications as well as negative effects on capacity for labor and reproductive fitness (Temple and Goodman 2014). Finally, the arrows in Figure 5 that feedback into environment and culture demonstrate how the sociocultural and biological effects of population stress may perpetuate the original stressors and lower host resistance.

The Impact of Stress on Subadult Growth and Development

The developing human body demonstrates remarkable plasticity by slowing growth in response to events of stress. When a physiological disturbance, such as nutrient deprivation, occurs, energy can be temporarily allocated away from developmental growth and toward the release of nutrient stores and tissue maintenance (Goodman *et al.* 1984; Huss-Ashmore *et al.* 1982). In general, physiological stress causes a shift in energetic trade-offs, often at the expense of body growth and protection from disease (Kuzawa 2007; Snodgrass 2012; Temple and Goodman 2014). Growth deficits during infancy, the stage of highest growth velocity, have the greatest impact on adult size (Kuzawa 2007; Lejarraga 2012). During this period, the hormones responsible for early life growth are highly sensitive to nutritional stress (Huss-Ashmore *et al.* 1982; Kuzawa 2007). The nutritional, metabolic, and growth status of individuals in early life has a significant impact on the adult condition, and in fact, most epigenetic influences on adult stature are present by three years of age (Kuzawa 2007; Lejarraga 2012). Rate of weight gain in early life has been shown particularly to influence adult size as well as the timing of developmental milestones (Lejarraga, 2012).

Environment and activity can impact growth deficits in body weight in various ways. Stressors causing changes in weight disproportionately affect certain tissues and somatic resources (Lejarraga 2012). Overuse resulting in muscle hypertrophy causes weight gain, whereas muscular atrophy due to lack of activity results in weight loss (Lejarraga 2012). Dehydration decreases weight due to loss of body water. Inadequate nutrition foremost affects body fat, resulting in weight loss (Lejarraga 2012).

Wasting, or emaciation, is an acute condition reflecting current nutritional status that refers to deficits in lean body mass relative to height and increased susceptibility to disease (Lejarraga 2012; WHO 1995). Body mass index (BMI), a measurement of weight in kilograms per unit height in meters (W/H^2), serves as a universal indicator of nutritional status, including underweight, overweight, and obese (Lejarraga 2012; Norgan *et al.* 2012; WHO 1995). Growth stunting, on the other hand, is a chronic condition that describes short height for age—but normal weight for height—as a consequence of nutritional deficits in early life (Lejarraga 2012; WHO 1995). In other words, growth stunting does not necessarily imply current nutritional stress, but indicates chronic malnourishment during the most sensitive stages of growth (Cole 2003; Kuzawa 2007; Lejarraga 2012; WHO 1995). Adult stature therefore represents the interplay between genetic potential for body size and sustained childhood living conditions (Cole 2003; Kuzawa 2007; WHO 1995).

Given a strong genetic potential for adult size, growth in the absence of environmental constraints tends to proceed faithfully within a particular centile (Cameron 2012). Environmentally or culturally induced stressors experienced during subadult growth, however, may cause delays or temporary gaps in growth (Cameron 2012). When an individual recovers from the physiological insult, they exhibit rapid growth in body size that restores their growth status to the expected percentile given their parents' size (Cameron 2012; Tanner 1981). This phenomenon is known as catch-up growth (Cameron 2012; Tanner 1981).

Catch-up growth in weight is not observed to the same degree as in height.

In fact, growth delays in weight during childhood may be unresolved or worsened as an individual reaches adulthood (Norgan *et al.* 2012). For Norgan *et al.* (2012), weight deficits bear a greater burden on lifelong health and quality of life. Total body weight relative to age and height are considered to be better indicators of work capacity than height alone (Norgan *et al.* 2012; WHO 1995).

A growth reference is a calibrated instrument used to assess growth status by comparison to population statistical distributions (Cole 2012). There is some controversy over the sampling of populations in the process of constructing growth references for international use (Cole 2012; Ruff 2002). Cole (2012) differentiates the use of a growth standard, a selected population of individuals with normal or healthy growth status, from the use of an unselected growth reference—in other words, a randomly selected population sample. Population variation further complicates the construction of growth charts. Growth stunting relative to international growth standards in certain populations may result from genetic, environmental, or cultural influences (Lejarraga 2012). These include poor health and nutrition and low birth weight over many generations (Lejarraga 2012), or clinal adaptation to certain environments over time in populations of shared ancestry (Ruff 2002).

For Cole (2012), a growth standard drawn from healthy individuals models the potential for growth for any given individual, in other words, the expectation for growth if environmental and socioeconomic conditions are optimal. The 2006 World Health Organization (WHO) Child Growth Standards demonstrate normal growth among an international selected sample of breast-fed children aged from birth to five years with unconstrained growth (Cole 2012; de Onis *et al.* 2007; Garza and de Onis 2004; WHO 2006). The Multicentre Growth Reference Study (MGRS) that produced these standards aimed to determine "how children *should* grow" universally, given that certain physiological requirements for growth and development are met (Garza and de Onis 2004:510). This "prescriptive approach" rests on an assumption that during infancy and until age five, interethnic discrepancies in growth and development are primarily environmental, rather than genetically controlled (Garza and de Onis 2004; Goode-Null 2002; Ruff *et al.* 2013). Anthropometric and developmental data were drawn from all major geographical regions, resulting in a credible growth standard appropriate for international use (Cole 2012; Garza and de Onis 2004).

According to the World Health Organization, interethnic variability and environmental factors complicate the use of growth standards beyond five years of age (de Onis *et al.* 2007). Genetic factors related to growth in body size become more evident during adolescence (Ruff *et al.* 2013). To account for increased genetic and environmental variation during this life stage, the 2007 WHO growth reference for individuals aged five to 19 years was constructed from a randomly selected population sample (de Onis *et al.* 2007). Utilizing the same data set, the 2007 WHO reference reconstructed the earlier 1977 NCHS/WHO growth reference to fit seamlessly with the 2006 WHO Child Growth Standards (de Onis *et al.* 2007; Hamill *et al.* 1977). This growth reference draws from a non-obese sample from the United States, which prevents overestimation of malnutrition due to the upward skewing of weight and BMI in modern populations with increasing obesity (de Onis *et al.* 2007). The growth reference is therefore optimized for detection of obesity among children and adolescents from all socioeconomic and ethnic groups (Cole 2012; de Onis *et al.* 2007).

The WHO growth charts are intended for use in both clinical and public health initiatives. In clinical assessments, the use of a population-specific growth standard is paramount in measuring the health of an individual relative to centiles of normal, healthy growth (Cole 2012).

As such, longitudinal growth standards for clinical use must reflect the child's specific ethnic, geographical, socioeconomic background (Cole 2012; Tanner 1976). This ensures that the deviations from expected growth based on parental stature necessary reflect health status, rather than baseline socioeconomic status or population genetics. The WHO Child Growth Standards ensure accurate clinical assessment at the life stage when growth and developmental delays are most critical (Cole 2012; Lejarraga 2012).

For public health assessments that investigate the growth status of a particular group of children or compare growth status between groups of children, a cross-sectional growth reference that demonstrates typical growth in a diverse population is most appropriate (Cole 2012; Tanner 1976). The distribution of growth status for a given group of children relative to the growth reference serves as an indicator of nutritional status irrespective of any one individual's growth status (Cole 2012). The use of a growth reference for public health assessment, as opposed to a growth standard, also negates individual variation surrounding the timing and severity of the adolescent growth spurt (Tanner 1976). Researchers have agreed that a randomly selected cross-sectional anthropometric dataset that proportionally reflects the ethnic diversity of an entire population can serve as a versatile reference (de Onis *et al.* 2007; Hamill *et al.* 1977; Ruff 2002; Stoudt *et al.* 1965). Limiting comparison of groups of individuals to specific datasets for populations of shared ancestry introduces the disadvantage of small sample sizes and bias from recent fluctuations in diet and lifestyle (Ruff 2002).

Bioarchaeologists interested in the growth and development of past populations have employed techniques to estimate body mass, stature, and cortical bone growth from subadult skeletal remains (Hummert 1983; Ruff *et al.* 2013; Saunders 2008). Researchers have also used these parameters to estimate BMI in modern (Ruff 2002) and medieval (Siegmund and

Papageorgopoulou 2011) archaeological samples, in order to assess the nutritional status, body composition, and activity patterns of past populations. These techniques rely on principles of human biomechanics and the mechanisms by which nutrition and growth in soft tissue mass influence the growth of skeletal tissues (Hummert 1983; Ruff *et al.* 2013; Saunders 2008).

Bone Functional Adaptation and Biomechanics

The plasticity of skeletal tissues in response to physiological stress and strenuous labor has been well documented in human skeletal biology. For Ruff (2006), "bone functional adaptation," frequently called Wolff's Law, describes changes in living bone morphology in response to dynamic muscle stress within an individual's lifetime. Physiological stress occurs when muscular strain reaches the limit of homeostatic control (Temple and Goodman 2014). When muscular strain exceeds "optimal customary strain level", bone deposition occurs, and when it falls short, bone resorption occurs (Ruff 2008:184). In other words, overuse of muscles causes new bone formation, while lack of muscle use allows for bone loss.

The morphology of skeletal remains serve as an imprint not only of muscular use during life, but also of baseline muscle mass and body weight. For Ruff (2008:188), skeletal robusticity characterizes "the strength or rigidity of a structure relative to the mechanically relevant measure of body size." Simply put, skeletal strength, or robusticity, describes the capacity of bone to withstand physiologically relevant forces. Overall body mass applies a mechanical force of magnitude equal to the "resistance of the skeleton to gravity" (2008:188). According to Newton's second law, force is the product of mass and acceleration. A non-accelerating body of mass must have force vectors of equal magnitude opposing any applied force. As such, body weight can be conceptualized as the total magnitude of force applied by the human skeleton to resist acceleration due to gravity of its center of mass.

$$W = m * g$$

W = body weight in Newtons (N)
M = body mass in grams (g)
g = acceleration due to gravity = 9.81 m/s^2

Wolff's Law dictates that increased peripheral bone formation occurs in response to increased strain on bone (Ruff 2006). Wider bone dimensions confer greater bone strength to oppose greater mass of living tissues. Human body mass therefore varies in direct proportion to certain skeletal dimensions.

Body Mass Estimation

Researchers have used this reasoning to develop reliable methods for estimating body mass from the human skeleton. For example, "biomechanical" and "morphometric" approaches extrapolate body mass from breadth measurements of the femur, and from the relationship between stature and bi-iliac breadth, respectively (Auerbach and Ruff 2004; Grine *et al.* 1995; McHenry 1992; Ruff 2007; Ruff *et al.* 1991). More recent studies of body mass estimation have used computed tomography (CT) and cross-sectional geometry to investigate skeletal robusticity from cortical bone thickness (Hummert 1983; Macintosh *et al.* 2013; Moore 2008; Moore and Schaefer 2011; O'Neill and Ruff 2004; Rantalainen *et al.* 2013; Ruff 2008). Because CT and radiographic scans were not conducted as standard procedure for the remains interred at the African Burial Ground, cross-sectional geometry cannot be calculated and used to estimate body mass for this population. Regression formulas for body mass estimation from dimensions of the human femur, however, provide a feasible method for estimating body mass using metrics described in Buikstra and Ubelaker's (1994) *Standards* (Auerbach and Ruff, 2004; Grine *et al*. 1995; McHenry, 1992; Ruff, 2007; Ruff *et al*. 1991).

CHAPTER IV.

MATERIALS AND METHODS

Materials

The materials used for this research fall under two categories—data generated by the osteological analysis of skeletal remains from the New York African Burial Ground, and anthropometric reference data for various age cohorts from national and international health organizations. Anthropometric and demographic data for these skeletal remains were originally collected as a component of the New York African Burial Ground Project conducted by Howard University and the U.S. General Services Administration (GSA). These data were accessed through the New York African Burial Ground SPSS database and digitized burial files, courtesy of Dr. Michael Blakey and the Institute for Historical Biology, College of William and Mary, Williamsburg, Virginia.

Adult and subadult samples from the New York African Burial Ground skeletal population were selected according to available anthropometric and demographic data. These samples are presented in Table 1. The primary selection factor for both samples was sufficient skeletal preservation to yield the specific femoral breadth measurements required for body mass estimation. These measurements include the breadth of the femoral metaphysis, or femur width, for individuals with age estimates from birth to 13 years, and femoral head breadth, or the maximum femoral head diameter, for individuals with age estimates above 13 years (Table 1) (Auerbach and Ruff 2004; Ruff 2007; Ruff *et al.* 1991; Sciulli and Blatt 2008). Individuals with indeterminate age were excluded from both samples in order to assess growth and age-specific changes in body mass. Adult individuals with indeterminate sex were excluded to control for sex differences in body mass. The adult population sample for whom maximum femoral head diameter, sex, and age estimates were available included 69 males and 41 females (Table 1). The subadult population sample included nine younger individuals of indeterminate sex and 10 older individuals (six males and four females) for whom femoral width and maximum femoral head diameter, respectively, were available (Table 1). Five individuals aged 18 to 19 years were included in both the adult and subadult samples for the purpose of comparison with data from the 2007 WHO Growth Reference (birth to 19 years) as well as the 1960-1962 United States National Health Examination Survey (18 to 79 years) (Table 1).

TABLE 1. New York African Burial Ground study sample by sex and age

Age Group	Sex	Number of Individuals
Adult (≥18 years)	Male	n=69[a]
	Female	n=41[b]
Subadult (birth – 13 years)	Indeterminate	n=9
Subadult (13 – 19 years)	Male	n=5[a]
	Female	n=4[b]

[a] Burial 427 was included in both the adult male and adolescent subsamples.
[b] Burial 259, 122, 205, and 316 were included in both the adult female and adolescent subsamples.

Two main sources of reference data for age- and sex-specific body mass distributions were also included in this analysis for comparison with the adult and subadult New York African Burial Ground population samples. Adult body weight percentiles for individuals aged 18 to 79 years were drawn from the first cycle of the United States National Health Examination Survey, conducted between 1960 and 1962 (Stoudt *et al.* 1965). These data were accessed through the internet archives of the Center for Disease Control and Prevention, National Center for Health Statistics. The 1960-1962 survey recorded weight using an automatic balancing scale for males and females from the age cohorts shown in Table 2 (Stoudt *et al.* 1965). This randomly selected sample reflects ethnic variation in equal proportions to the civilian population in all parts of the United States during this two year survey period (Stoudt *et al.* 1965).

TABLE 2. 1960-1962 National Health Examination Survey sample by sex and age [a]

Age	Male	Female
18 – 24 years	411	534
25 – 34 years	675	746
35 – 44 years	703	784
45 – 54 years	547	705
55 – 64 years	418	443
65 – 74 years	265	299
75 – 79 years	72	70
Total	3,091	3,581

[a] Compiled from Stoudt *et al*. (1965).

Subadult growth reference datasets for individuals aged from birth to 19 years were downloaded online from the World Health Organization (2015b). The 2006 WHO Child Growth Standards provides international percentile statistics of body weight and body mass index (BMI) for each month interval up to five years of age in breast-fed children with unconstrained growth (Cole 2012; de Onis *et al.* 2007; Garza and de Onis 2004; WHO 2006). This resource was produced by the Multicentre Growth Reference Study (MGRS), which collected longitudinal and cross-sectional anthropometric data from populations in Brazil, Ghana, India, Norway, Oman, and the United States (Garza and de Onis 2004; WHO 2006). The 2007 WHO Growth Reference, on the other hand, presents national body weight and BMI percentiles for randomly selected individuals aged five to ten years and five to 19 years, respectively, drawing from the 1977 publication, *NCHS Growth Curves for Children Birth – 18 Years* (de Onis *et al.* 2007; Hamill *et al.* 1977). This growth reference was reconstructed to allow for a smooth transition from the 2006 WHO Child Growth Standards. The 2006 WHO Child Growth Standards and 2007 WHO Growth Reference study samples used to construct weight-for-age and BMI-for-age percentiles are summarized in Table 3.

TABLE 3. 2006 World Health Organization (WHO) Child Growth Standards and 2007 WHO Growth Reference samples by sex and anthropometric indicator [a]

Dataset	Anthropometric Indicator	Females	Males
2006 WHO Child Growth Standards	Weight-for-age	n=14,056	n=13,797
	BMI-for-age	n=13,623	n=13,362
2007 WHO Growth Reference [b]	Weight-for-age BMI-for-age	n=11,151	n=11,089

[a] Compiled from de Onis *et al.* (2007) and the World Health Organization (2006).
[b] This value accounts for 356 females and 321 males who were excluded as outliers.

Methods

Methods are presented here for the estimation and assessment of (1) achieved body mass and body mass index (BMI) in skeletally mature adults, and (2) body mass growth status and BMI in subadults from the New York African Burial Ground. Established regression formulas were used to estimate body mass in all adult remains from the NYABG with sufficient preservation of postcranial elements. Table 4 lists four sets of adult body mass prediction equations from three bioarchaeological sources, as well as the demographic composition of the population samples from which they were derived (Auerbach and Ruff 2004; Grine *et al.* 1995; McHenry 1992; Ruff *et al.* 1991). These equations follow a "mechanical" approach of body mass estimation that uses femoral head breadth as a single variable[1] (Auerbach and Ruff 2004).

TABLE 4. Body mass estimation equations for adult skeletal remains from Auerbach and Ruff (2004)

Source	Equation [a]	Sample Composition
Ruff, *et al.* (1991)	BM = (2.741 × FH – 54.9) × .90 (males) BM = (2.426 × FH – 35.1) × .90 (females) BM = (2.160 × FH – 24.8) × .90 (combined sex)	Based on data for 80 individuals taken from a population from Baltimore, MD
McHenry (1992)	BM = 2.239 × FH – 39.9	Based on 4 sample means of North American males and females, African Pygmies, and Khoisan
Grine, *et al.* (1995)	BM = 2.268 × FH – 36.5	Based on 10 sex-specific means for samples of large-bodied African Americans, European Americans, and Native Americans

[a] BM = body mass in kilograms, FH = femoral head anterior-posterior breadth (mm).

Each published formula offers different advantages. Ruff *et al.* (1991) presented both sex-specific and combined-sex formulas that comparatively illuminate the significance of sexual

[1]The authors also provided one equation for the "morphometric" method, using both stature and bi-iliac breadth (BIB). BIB can be measured on an osteometric board by rearticulation of the ossa coxae with the sacrum (Auerbach and Ruff, 2004). Because the researchers of the NYABG Project did not measure bi-iliac breadth, this equation has been omitted.

dimorphism in this population. Grine *et al.* (1995) and McHenry (1992) based their regression equations on sample means for populations of varied ancestry, including continental African and African American groups of varying average population body size. Researchers have also demonstrated the value of averaging estimated values from all three authors, whose formulas tend to overestimate or underestimate body mass, given the diversity of their samples (Table 6) (Auerbach and Ruff 2004; Pomeroy 2012; Ruff, *et al*. 2012). In this research, body mass was estimated for each skeletally mature NYABG adult with measurable femoral head dimensions using:

(A) One sex-specific formula (Ruff *et al.* 1991), and

(B) Three combined-sex formulas (Grine *et al.* 1995; McHenry 1992; Ruff *et al.* 1991).

The averages of these four estimates for each individual were used for all subsequent analyses. Individual body mass estimates were compared graphically with male and female adult weight-for-age percentiles from the 1960-1962 National Health Examination Survey (NHES).

Stature estimates were calculated for adult individuals with sufficient long bone preservation for the purpose of body mass index calculation. Following Goode-Null *et al.* (2009), sex-specific regression equations (Table 5) for individuals of African ancestry aged 18 to 30 years were used to estimate living stature from the maximum length of the femur (Fig. 6). These equations were derived from African American males and females from the Terry Collection, as well as a sample of African American male military personnel who served during World War II and the Korean War (Trotter 1970; Trotter and Gleser 1952).

TABLE 5. Stature estimation equations for adults of African ancestry from Trotter (1970)

Sex	Living Stature Estimation (cm)[a]	Std. Error of Estimate
Male	$2.11\ Fem_m + 70.35$	± 3.94
Female	$2.28\ Fem_m + 59.76$	± 3.41

[a] Fem_m = Maximum femur length in centimeters.

Body mass index was calculated for all NYABG adult males (n=34) and females (n=20) for whom body mass and living stature estimates were available, using the following equation:

$$\mathbf{BMI = W/H^2}$$

where W = body mass estimate in kilograms (kg)
H = stature estimate in meters (m)

All statistical analyses of adult body mass, stature, and BMI estimates were conducted with IBM SPSS Statistics 21 software. Male (n=69) and female (n=41) adult body mass estimates as well as male (n=30) and female (n=20) BMI values were treated as separate samples and tested for normality using Shapiro-Wilk and Kolmogorov-Smirnov tests with a Lilliefors significance correction for unknown variances. Based on an assumption of normality, male and female mean body mass estimates were then compared with the 1960-1962 National Health Examination Survey (NHES) sample means for males and females of 18 to 79 years of age using a two-tailed one-sample T-test. This statistical method tested the null hypothesis that there are no statistically significant within-sex differences in mean body mass between the NYABG adult population and the National Health Examination Survey sample (H_0: μ[NYABG] = μ[NHES]; H_1: μ[NYABG] ≠ μ[NHES]). To assess among-sex mean differences in body mass for the NYABG male and female samples, a two-tailed independent-samples T-test was conducted given (1) equal variances assumed, and (2) equal variances not assumed. A Levene's test for equality of variances was performed in the former case to validate this assumption.

The distribution of BMI among NYABG individuals aged 18 years and older was assessed relative to the WHO international classification of underweight, overweight, and obese (Table 6) (Nishida 2004; WHO 2015a). According to the World Health Organization, adult BMI values are independent of age and sex within a population (Nishida 2004). Mean differences in BMI between the sexes may therefore correspond with underlying differences in body composition and nutritional status. To investigate the possibility of sex differences in BMI, the null hypothesis that there is no statistically significant difference in NYABG male (n=34) and female (n=20) BMI estimates was tested with a two-tailed independent-samples T-tests, following the same assumptions and methods for the among-sex T-test of mean body mass.

TABLE 6. International World Health Organization BMI cut-offs for adult underweight, overweight, and obesity [a]

Classification	BMI Range (kg/m^2)
Obese	≥30.00
Overweight	≥25.00
Normal Range	18.50 – 24.99
Underweight	<18.50

[a] BMI Cut-offs are independent of age and sex within a population.

The subadult samples were analyzed using a similar approach, albeit forgoing statistical analysis due to very small sample sizes for each age cohort. Ruff (2007) pioneered the estimation of body mass in subadult human remains using distal femoral metaphyseal breadth in individuals aged from birth to 13 years and femoral head breadth in individuals aged from seven to 17 years (Fig. 6). Age-specific regression formulas using these skeletal metrics were constructed using a body mass and radiograph data from a subsample of the Denver Growth Study, a longitudinal growth study that measured children of European ancestry throughout their entire phase of skeletal growth (Ruff 2007). Table 7 lists subadult body mass estimation equations from ordinary least squares regression of two dimensions of the developing femur for each year of age, which includes all individuals aged within 0.5 years of a given age (Ruff 2007).

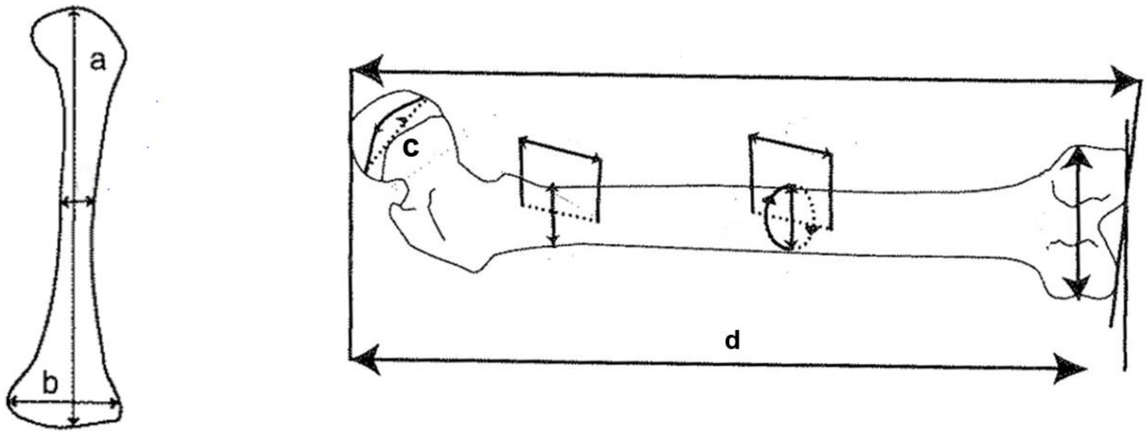

Fig. 6. Selected anthropometric measurements of the immature (left) and mature (right) human femur (adapted from Buikstra and Ubelaker 1994). These include (a) length—maximum length of immature diaphysis, (b) width—maximum width of immature distal metaphysis, (c) maximum head diameter, and (d) maximum length.

TABLE 7. Subadult body mass estimation equations from Ruff (2007)

	Log_e(Femoral metaphyseal breadth)				Log_e(Femoral head breadth)			
Age (years)	Slope	Int.	%SEE[c]	SEE	Slope	Int.	%SEE	SEE
1	0.751	-0.45	7.10	0.64				
2	0.994	-1.28	4.80	0.56				
3	0.899	-0.86	4.80	0.65				
4	1.048	-1.35	6.50	1.02				
5	1.096	-1.47	6.20	1.09				
6	1.034	-1.16	6.60	1.32				
7	1.095	-1.33	6.30	1.43	0.650	0.92	6.2	1.41
8	1.010	-0.90	9.20	2.32	0.749	0.64	7.9	2.01
9	1.524	-2.89	14.40	4.13	1.286	-1.12	11.3	3.24
10	1.939	-4.55	15.80	5.02	1.374	-1.41	13.9	4.42
11	1.69[a]	-3.46	18.00	6.45	1.582	-2.11	14.7	5.28
12	2.263	-5.82	17.96	6.97	1.725	-2.62	13.5	5.31
13	1.766[a]	-3.67	19.70	8.74	1.656	-2.35	16.7	7.41
14					1.226	-0.68	14.9	7.44
15					–[b]	–	–	–
16					0.842[a]	0.88	13.6	6.03
17					1.327	-0.94	11.4	7.01

[a] Regression near-significant ($0.05 < p \leq 0.10$).
[b] $p > 0.10$; no equation given.
[c] SEE = standard error of estimate.

Sciulli and Blatt (2008) have since confirmed the precision and accuracy of these equations using a group of subadult remains brought to the Franklin County, Ohio coroner from 1990-1991. Unlike the Denver Growth Study population used initially by Ruff (2007) to develop these regression equations, the Franklin County sample consisted of approximately 25 percent African American children and greater variability of socioeconomic status (Sciulli and Blatt 2008). This sample also included individuals who died as a result of disease and trauma (Sciulli and Blatt 2008). The researchers found that these equations were reasonably accurate in estimating body mass for non-obese individuals, which describes most archaeological populations (Ruff *et al.* 2013; Sciulli and Blatt 2008).

In the present analysis, the log-transformed equations (Ruff 2007) were used to estimate body mass for each New York African Burial Ground subadult with available femur width measurements (aged from birth to 13 years, n=9), and femoral head breadth measurements (aged from 14 to 19 years, n=9). Table 7 demonstrates that for individuals aged seven to 13 years, both methods are possible, though femoral head breadth yields a consistently lower standard error of estimate (Ruff 2007). Ruff (2007) explains that femoral head breadth more accurately reflects articular size. Distal metaphyseal breadth only measures the medial-lateral size of the articulation, whereas maximum femoral head breadth is taken at whichever orientation it occurs (Ruff 2007). However, only immature anthropometric measurements (Fig. 6, left) were taken for the New York African Burial Ground individuals who fell within in this age group, possibly due to the variable preservation of the femoral head epiphysis. According to Scheuer and Black (2004), fusion of the femoral head occurs on average at 14 years and two months in females, and 16 years and three months in males, and roughly coincides with the cessation of growth in height at skeletal maturity. Thus, body mass was estimated from distal metaphyseal breadth for all

NYABG individuals aged below 14 years, and from maximum femoral head breadth for all individuals aged 14 and older.

To assess body mass growth status of the population interred at the New York African Burial Ground, the body mass estimates for the younger subadult sample (n=9) were charted against weight-for-age centile curves from the 2006 WHO Child Growth Standards (ages one to five years) and the 2007 WHO growth reference (ages five to 10 years). The WHO weight-for-age statistics do not extend beyond ten years of age, due to the significant environmental and genetic variability of adolescent growth within and between the sexes (de Onis *et al.* 2007; Ruff 2007; Ruff *et al.* 2013; Tanner 1976). Body mass index, on the other hand, standardizes body mass per unit height, which allows for more reliable monitoring of body size and nutritional status during adolescence and at all ages (Lejarraga 2012; Norgan *et al.* 2012).

Subadult individual body mass index estimates were calculated from the subadult body mass estimates and stature estimates published by Goode-Null (2002). Individual BMI-for-age values were charted against BMI-for-age centile curves accessed from the 2006 WHO Child Growth Standards (birth to five years) and the 2007 WHO Growth Reference (five to 19 years). Nutritional status—specifically malnutrition—was assessed for the NYABG subadult sample using World Health Organization age-dependent cut-offs for stunted (low height-for-age) and wasted (low weight-for-height) (dos Santos *et al.* 2014; WHO 1995). Following dos Santos *et al.* (2014) and the World Health Organization (WHO) expert committee (1995), subadult anthropometric indicators were evaluated for stunting and wasting relative to the 2006 WHO Child Growth Standards and 2007 WHO Growth Reference normal distributions (Table 8).

TABLE 8. International World Health Organization criteria for assessing subadult stunting and wasting [a]

	Relevant Range of WHO Anthropometric Reference		
	Stunting	Wasting	Stunting and Wasting
Height-for-Age	≤ 5^{th} percentile	> 5^{th} percentile	≤ 5^{th} percentile
BMI-for-Age	> -2 SD	≤ -2 SD	≤ -2 SD

[a] Compiled from dos Santos *et al.* 2014 and the World Health Organization (1995).

It must be addressed that any analysis based on various measurements from human skeletal remains comes with inherent error. Every precaution was taken by researchers involved in the New York African Burial Ground Project to minimize potential errors. To control for inter-observer error, two sets of anthropometric measurements were performed for each burial by separate technicians. When the difference exceeded five percent of the averaged measured value, a third set of measurements was taken (Blakey *et al.* 2009b). Furthermore, measurements were omitted for bones with extensive fragmentation, poor preservation and warping, except in cases where measurements could be approximated to account for minimal cortical bone damage (Blakey *et al.* 2009b). However, even negligible errors in anthropometric measurements were likely magnified in this analysis by the estimation of body mass and stature using regression equations, as well as the calculation of body mass index from the derived body mass and stature estimates. Minor weathering of skeletal remains, for example, may have resulted in slightly misrepresentative measurements that could more drastically skew body mass index estimates.

CHAPTER V.
RESULTS

Adult Body Mass

This section presents the results of body mass and BMI estimation and analysis in the adult and subadult population samples from the New York African Burial Ground. The distributions of adult male and female body mass and BMI are characterized by descriptive statistics and tests for normality, and compared for mean differences between the sexes. The New York African Burial Ground mean adult body mass estimates are also compared with the 1960-1962 National Health Examination Survey means. Adult and subadult samples are compared graphically with anthropometric reference data percentiles to visually assess age-specific rankings in body mass and body composition.

The descriptive statistics for body mass estimates of New York African Burial Ground adult male and female samples are shown in Table 9. Mean male and female body mass estimates were 67.08 kg, and 59.87 kg, respectively (Table 8). The 95% confidence intervals for mean body mass do not overlap for the male and female samples. In both sexes, the five percent trimmed means and medians agree closely with the sample means, and skewness and kurtosis are close to zero. These statistics suggest that the sample distributions are approximately normally distributed.

TABLE 9. Descriptive statistics for New York African Burial Ground adult male and female body mass estimates

Body Mass (kg)		Male (n=69)	Female (n=41)
Mean		67.080	59.866
Std. Error of Mean		0.773	0.902
95% Confidence Interval for Mean	Lower Bound	65.537	58.043
	Upper Bound	68.623	61.690
5% Trimmed Mean		67.095	59.678
Median		67.608	60.652
Variance		41.260	33.363
Std. Deviation		6.423	5.776
Skewness		-0.109	0.374
Std. Error of Skewness		0.289	0.369
Kurtosis		-0.151	0.462
Std. Error of Kurtosis		0.570	0.724

Figures 7 – 9 and Table 10 present further graphical and statistical tests of normality for male and female body mass estimates. Adult body mass histograms for both the male (n=69) and female (n=41) samples from the New York African Burial Ground correspond fairly closely with the expected normal distribution (Fig. 7). Individual body mass estimates show a strong linear relationship when charted against the expected normal (Fig. 8). Potential outliers shown by the normal probability plots (Fig. 8) and detrended normal plots (Fig. 9) for both samples were checked for errors, and none were omitted. The Shapiro-Wilk test failed to reject the null hypothesis that male and female body mass estimates are normally distributed (p=0.694, p=0.565, respectively) (Table 10). These analyses therefore validate the assumption that body mass estimates distribute normally for both sexes.

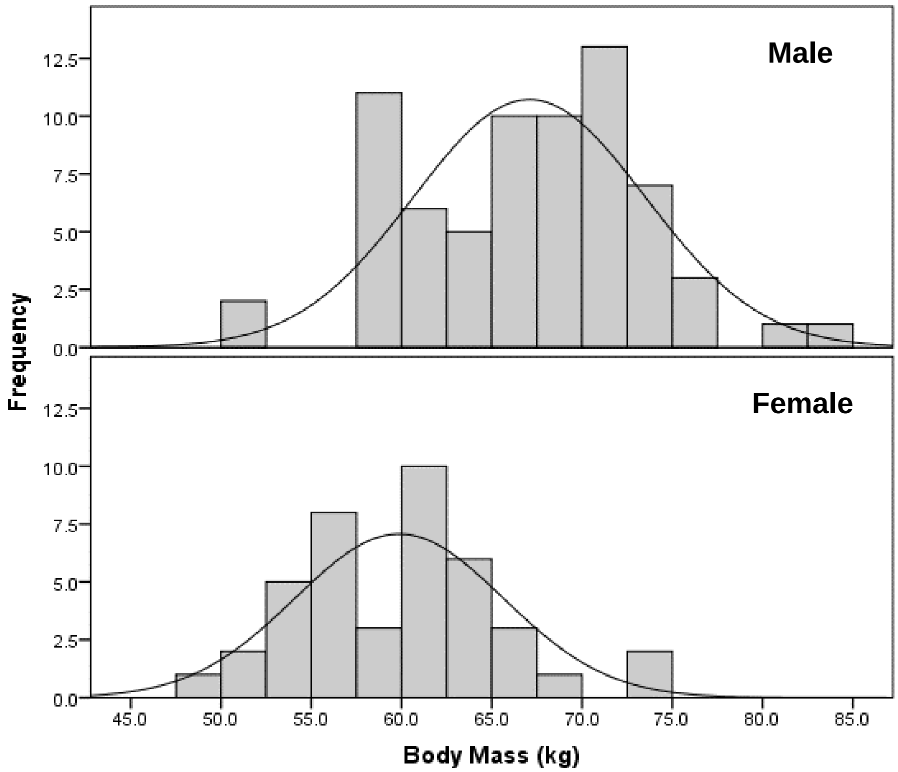

Fig. 7. New York African Burial Ground adult male (n=69) and female (n=41) body mass distributions**.** The solid line represents the expected normal distribution.

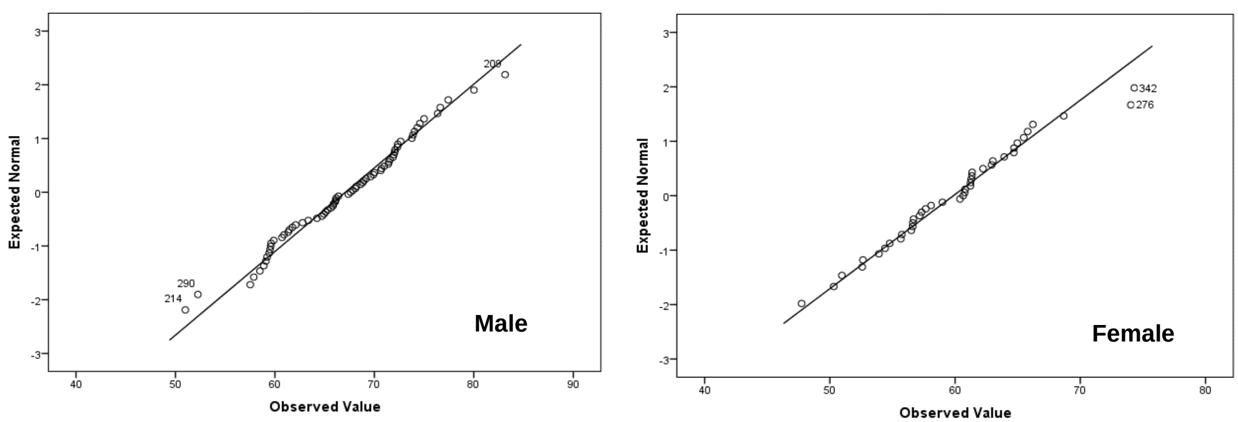

Fig. 8. Normal probability plots for New York African Burial Ground adult body mass estimates**.** For both the male and female samples, the observed values align closely with the expected normal. Potential outliers are labelled by NYABG burial number.

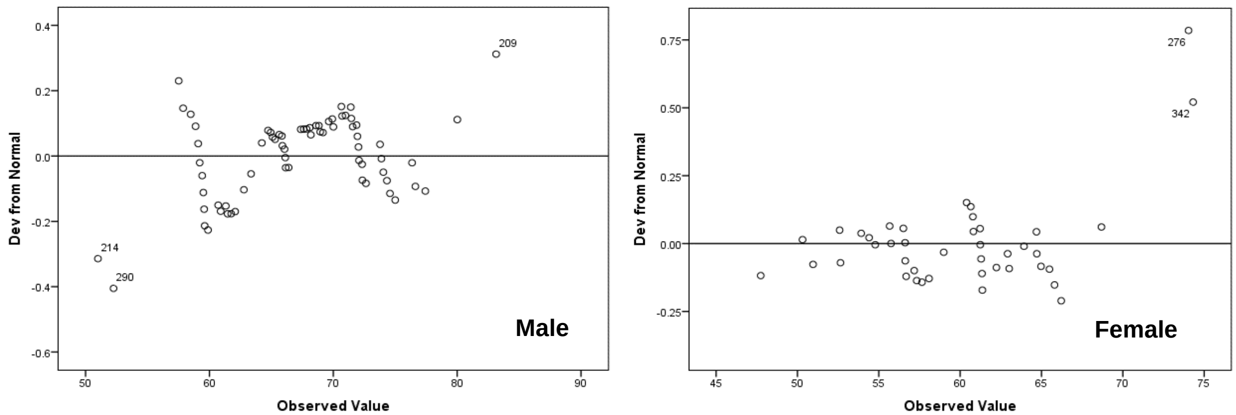

Fig. 9. Detrended normal probability plots for New York African Burial Ground adult male and female body mass estimates. Potential outliers are labelled by NYABG burial number.

TABLE 10. Tests for normality of New York African Burial Ground adult male and female body mass distributions

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
Sex	Statistic	df	*p*-value[b]	Statistic	df	*p*-value[b]
Male	0.059	69	0.200	0.987	69	.694
Female	0.081	41	0.200	0.977	41	.565

[a] Lilliefors significance correction.
[b] Significance at $p \leq 0.05$.

Given the assumption of a normal distribution for each adult sample, the mean difference in body mass between males and female was demonstrated both graphically and statistically. The box-plot in Figure 10 visually compares the male and female mean body mass estimates with their associated distributions. Two female individuals with unusually high body mass estimates were checked for errors and were not omitted from subsequent analyses. Table 11 summarizes the results of a two-tailed independent-samples T-test to quantify mean difference in body mass between the male and female samples. Levene's test for homogeneity of variance indicted that male and female variances can be assumed equal (p=0.331). The difference in mean male and female body mass was highly statistically significant ($p < 0.001$).

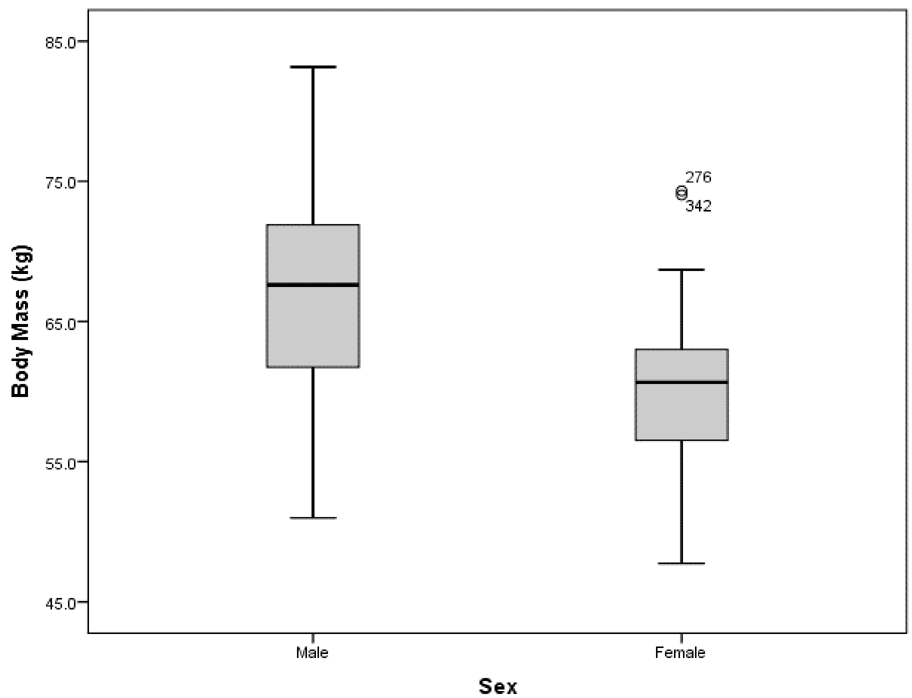

Fig. 10. Box-plot of New York African Burial Ground male and female body mass estimates. Outliers are labelled by NYABG burial number.

TABLE 11. Independent-samples T-test for mean differences in New York African Burial Ground adult male and female body mass estimates

	Statistic	Equal variances assumed	Equal variances not assumed
Levene's Test	F	0.953	–
	p	0.331	–
T-test for Equality of Means	t	5.908	6.071
	df	108	91.365
	p (2-tailed)	0.000[a]	0.000[a]

[a] $p < 0.001$.

Mean body mass for the New York African Burial Ground male and female samples were also were also compared with mean adult male and female body weight from the 1960-1962 National Health Examination Survey (NHES). The results of two-tailed one-sample T-tests for the NYABG male and female samples are shown in Table 12. For both sexes, the mean difference in adult body mass between the New York African Burial Ground and National Health Examination Survey samples were highly statistically significant ($p < 0.001$).

TABLE 12. One-sample T-tests for mean differences in New York African Burial Ground and 1960-1962 National Health Examination Survey adult male and female body mass

	NYABG Adult Male	NYABG Adult Female
Test Value (kg)[a]	76.204	64.410
t-statistic	-11.799	-5.037
df	68	40
p-value (2-tailed)	0.000[b]	0.000[b]

[a] Mean adult body weight from the National Health Examination Survey sample.
[b] $p < 0.001$.

Although mean adult body mass for the NYABG adult samples was shown to be statistically lower than mean adult body weight from the National Health Examination Survey for all individuals aged 18 to 79 years ($p < 0.001$) (Table 11), this analysis does not account for age-related changes in mean body mass. Figures 11 and 12 show the distribution of NYABG male (n=69) and female (n=41) body mass estimates relative to percentile rankings for every age cohort from the 1960-1962 National Health Examination Survey. Of the total NYABG adult male sample, there were 65 individuals (94%) whose body mass estimates fell beneath the 50th percentile ranking of body weight for their corresponding age cohort (Fig. 11). Six individuals (9%) fell below the fifth percentile, and one individual fell below the first percentile. The NYABG adult female sample, on the other hand, included 23 individuals (56%) whose body mass estimates fell beneath the 50th percentile ranking for their corresponding age cohort (Fig. 12). One individual (2.4%) fell beneath the fifth percentile ranking for body weight.

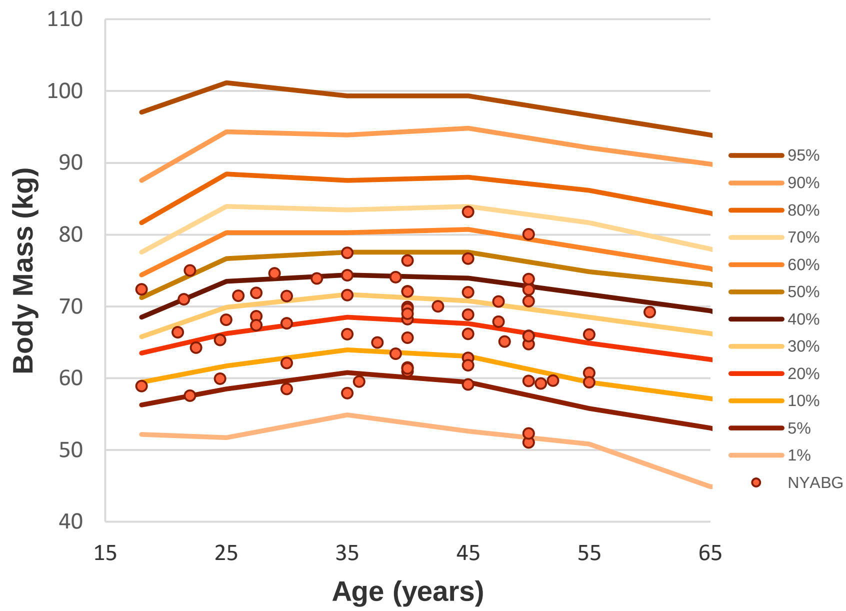

Fig. 11. New York African Burial Ground adult male body mass estimates charted against 1960-1962 National Health Examination Survey adult male weight-for-age percentiles.

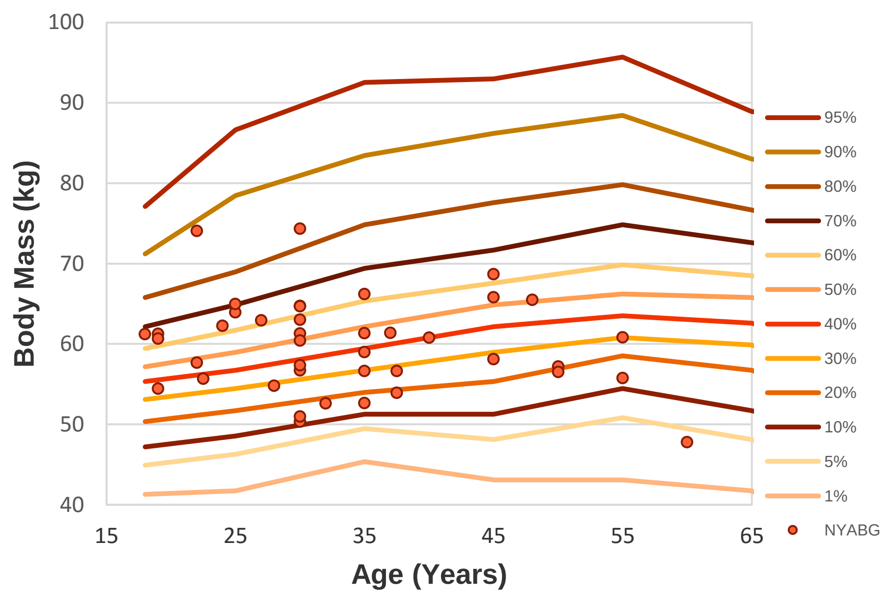

Fig. 12. New York African Burial Ground adult female body mass estimates charted against 1960-1962 National Health Examination Survey adult female weight-for-age percentiles.

Adult Body Mass Index

Descriptive statistics for the distribution of adult male (n=34) and female (n=20) body mass index (BMI) estimates are presented in Table 13. Sample means for adult male and female BMI estimates were 24.28 kg/m^2 and 23.42 kg/m^2, respectively. Skewness and kurtosis were close to zero, suggesting normally distributed data. Observed individual BMI estimates demonstrate a strong linear trend when charted against the expected normal (Fig. 13). Potential outliers shown by the normal probability plots (Fig. 13) and detrended normal plots (Fig. 14) for both samples were checked for errors, and were included in subsequent analyses. The Shapiro-Wilk test for normality, which was preferred in this case for sample sizes less than fifty, was not significant for either the adult male (p=0.778) or female (p=0.6910) samples (Table 14). The distributions of BMI estimates for both adult samples were therefore assumed to be normal.

TABLE 13. Descriptive statistics for New York African Burial Ground adult male and female body mass index estimates

BMI (kg/m^2)		Male (n=34)	Female (n=20)
Mean		24.277	23.420
Std. Error of Mean		0.323	0.394
95% Confidence Interval for Mean	Lower Bound	23.619	22.596
	Upper Bound	24.936	24.244
5% Trimmed Mean		24.304	23.425
Median		24.639	23.469
Variance		3.557	3.098
Std. Deviation		1.886	1.760
Skewness		-0.357	0.069
Std. Error of Skewness		0.403	0.512
Kurtosis		0.046	-0.330
Std. Error of Kurtosis		0.788	0.992

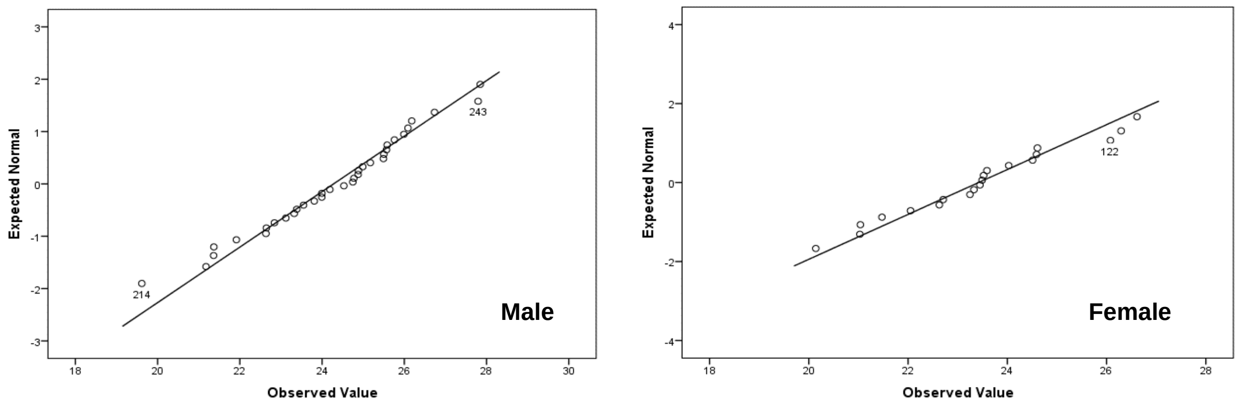

Fig. 13. Normal probability plots for New York African Burial Ground adult male and female body mass index estimates**.** Potential outliers are labelled by NYABG burial number.

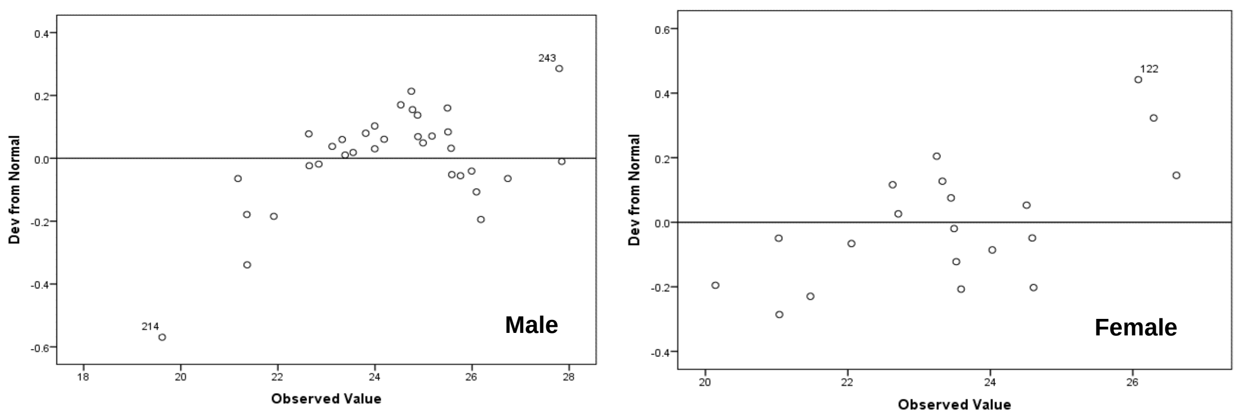

Fig. 14. Detrended normal probability plots for New York African Burial Ground adult male and female body mass index estimates. Potential outliers are labelled by NYABG burial number.

TABLE 14. Tests for normality of New York African Burial Ground adult male and female body mass index distributions

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
Sex	Statistic	df	*p*-value[b]	Statistic	df	*p*-value[b]
Male	0.098	34	0.200	0.980	34	0.778
Female	0.112	20	0.200	0.967	20	0.691

[a] Lilliefors significance correction.
[b] Significance at $p \leq 0.05$.

Figure 15 presents the frequency distributions of body mass index for the New York African Burial Ground adult male (n=34) and female (n=20) sample, compared with the World Health Organization principal cut-off points for the international classification of underweight, overweight, and obese (Nishida 2004; WHO 2015a). All adult male and female BMI estimates fell within the normal and overweight range. Mean BMI estimates (Fig. 13) fell within the normal range for both the adult male and female samples. A greater proportion of the male sample fell within the overweight range than that of the female sample.

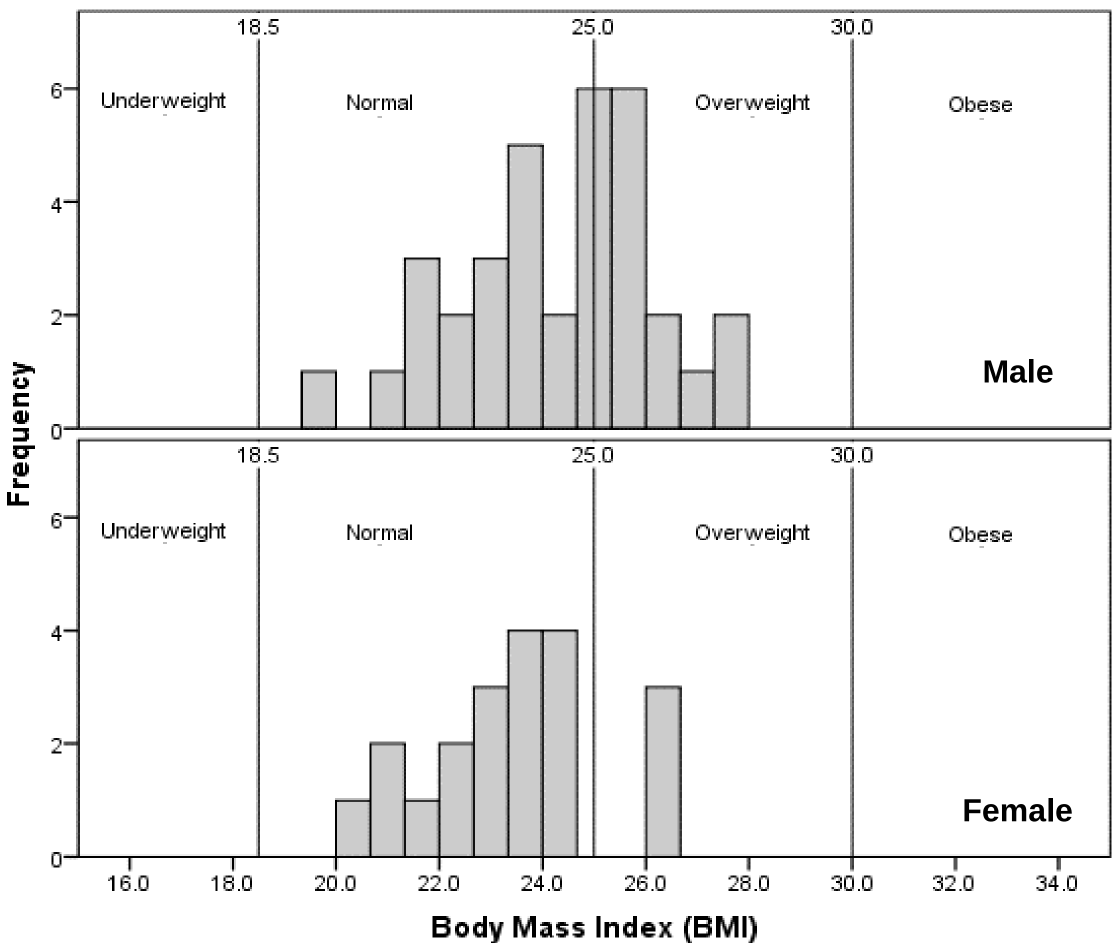

Fig. 15. New York African Burial Ground adult male (n=34) and female (n=20) body mass index distributions. The solid lines denote current World Health Organization principal cut-off points for the international classification of underweight, overweight, and obese.

Mean differences in BMI estimates between the New York African Burial Ground samples are represented visually in the box-plot in Figure 16. A two-tailed independent-samples T-test was performed to investigate whether a statistically significant difference in BMI existed between the male and female samples. The results of this analysis are summarized in Table 15. The assumption of equal variances was supported by Levene's test (p=0.556). Mean differences in male and female BMI estimates were not shown to be statistically significant (p=0.104).

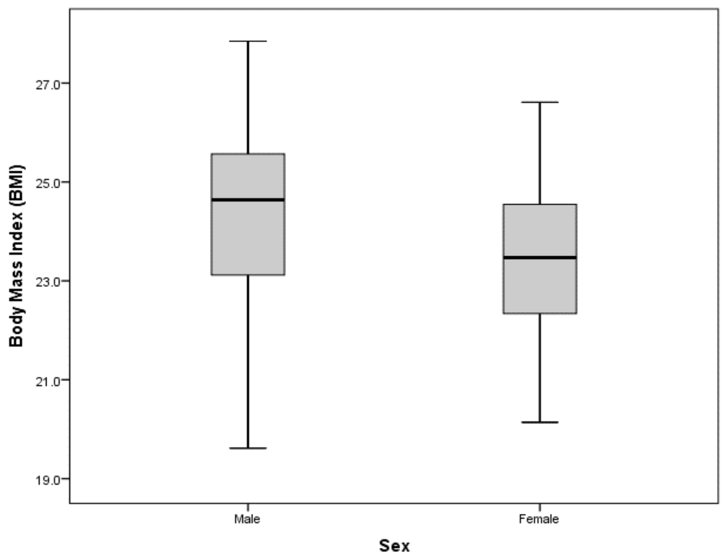

Fig. 16. Box-plot of New York African Burial Ground male and female body mass index estimates.

TABLE 15. Independent-samples T-test for mean differences in New York African Burial Ground male and female body mass index estimates

	Statistic	Equal variances assumed	Equal variances not assumed
Levene's Test	F	0.352	–
	p	0.556	–
T-test for Equality of Means	t	1.652	1.683
	df	52	42.236
	p (2-tailed)	0.104	0.100

Subadult Body Mass and Nutritional Status

Body mass, living stature, and body mass index (BMI) estimates for the subadult sample (n=18) from the New York African Burial were compared with the 2006 World Health Organization (WHO) Child Growth Standards and 2007 WHO Growth Reference percentile curves for weight-for-age (Fig. 17), height-for-age (Fig. 18), and BMI-for-age (Fig. 19), respectively. Body mass estimates fell unanimously below the 50th percentile for individuals younger than 10 years (n=9) (Fig. 17). The entire subadult sample (n=18), including adolescents, fell below the 50th percentile for height, with the exception of one infant aged just over one year (Burial 184, Fig. 18). However, like the adult sample, BMI estimates for children and adolescence mostly fell within one standard deviation of the mean, and some individuals exceeded the upper range (Fig. 19). Two individuals, aged just above one year and at nine years, showed BMI estimates that exceeded two standard deviations below the mean (Burials 184 and 95, Fig. 19).

The World Health Organization percentile and z-score rankings of body mass, stature, and BMI estimates for each New York African Burial Ground subadult individual are summarized in Table 16. Height-for-age and BMI-for-age rankings were compared to assess nutritional status. Six individuals (33%) within the total subadult sample (n=18) showed stunting alone, one individual (6%) showed wasting alone, and one individual (6%) showed both stunting and wasting. All four individuals with age estimates below four years showed either stunting or wasting. All seven individuals aged 17.5 years and older showed normal-range nutritional status. Among the individuals aged four to 17 years, three showed stunting alone, one showed stunting and wasting, and three showed normal-range nutritional status.

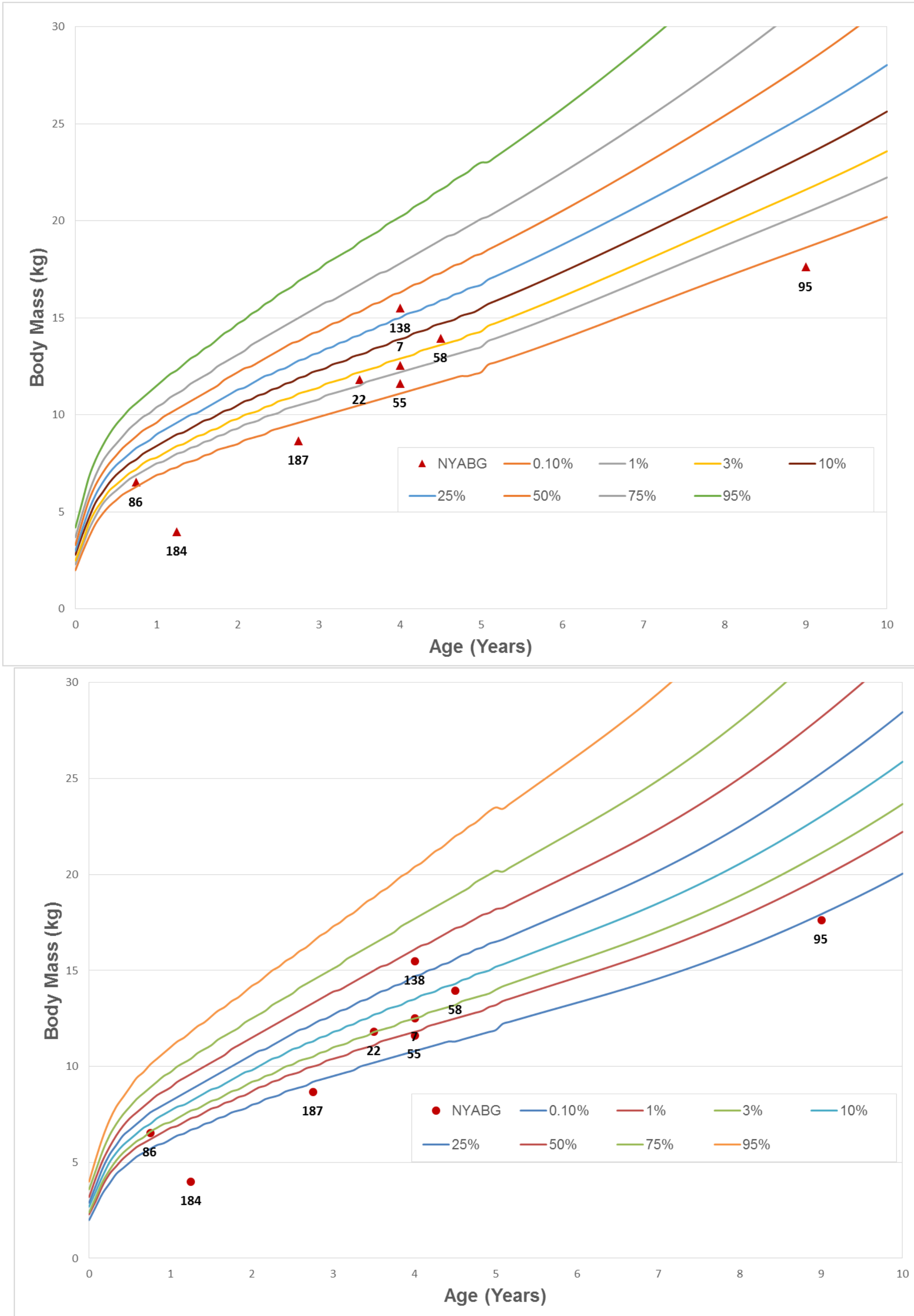

Fig. 17. New York African Burial Ground subadult body mass estimates charted against international weight-for-age percentiles from the 2006 World Health Organization (WHO) Child Growth Standards (birth to five years) and the 2007 WHO Growth Reference (five to 10 years) for males (top) and females (bottom). Individuals are labelled by NYABG burial number.

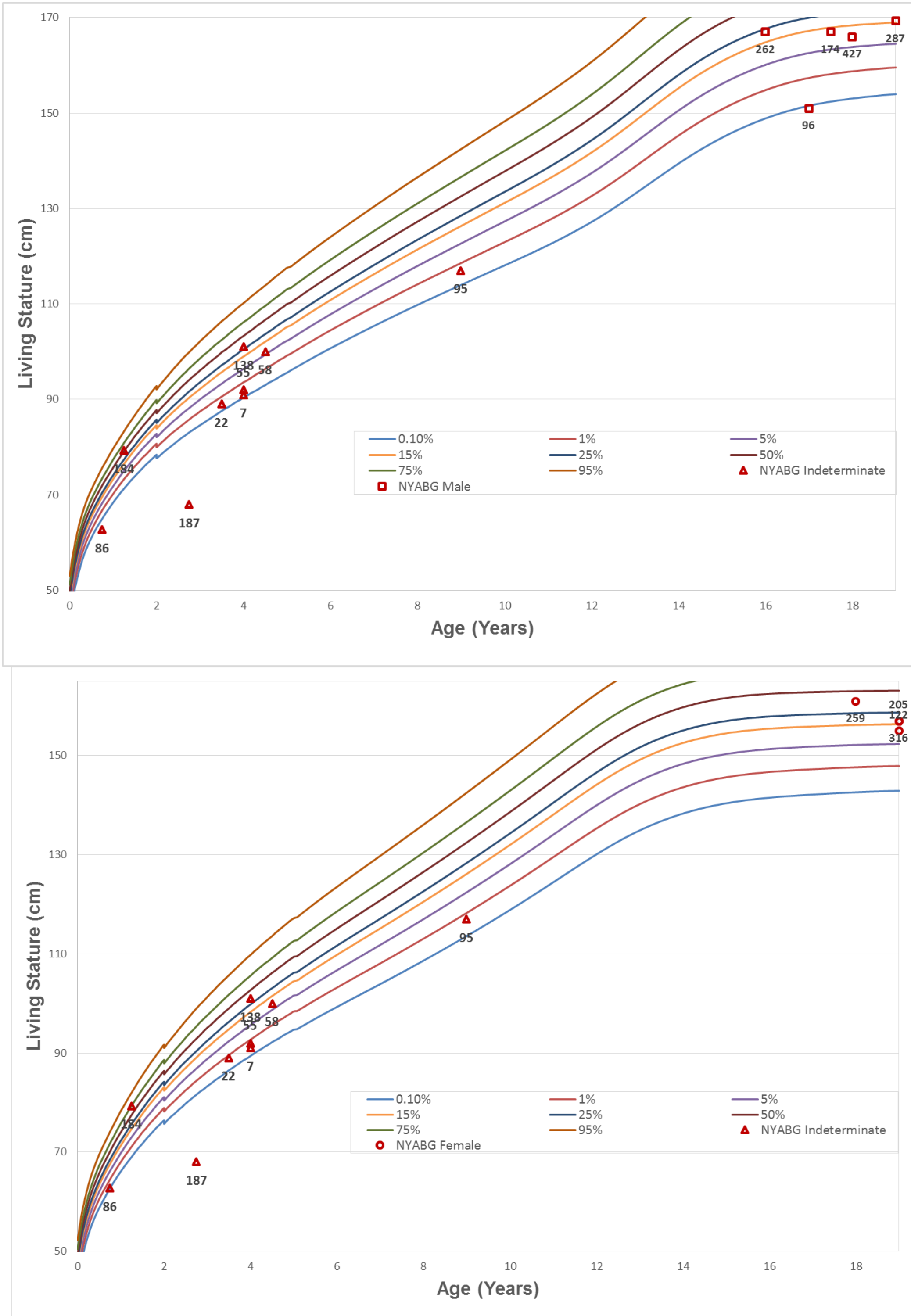

Fig. 18. New York African Burial Ground subadult living stature estimates charted against international height-for-age percentiles from the 2006 World Health Organization (WHO) Child Growth Standards (birth to five years) and the 2007 WHO Growth Reference (five to 19 years) for males (top) and females (bottom). Individuals are labelled by NYABG burial number.

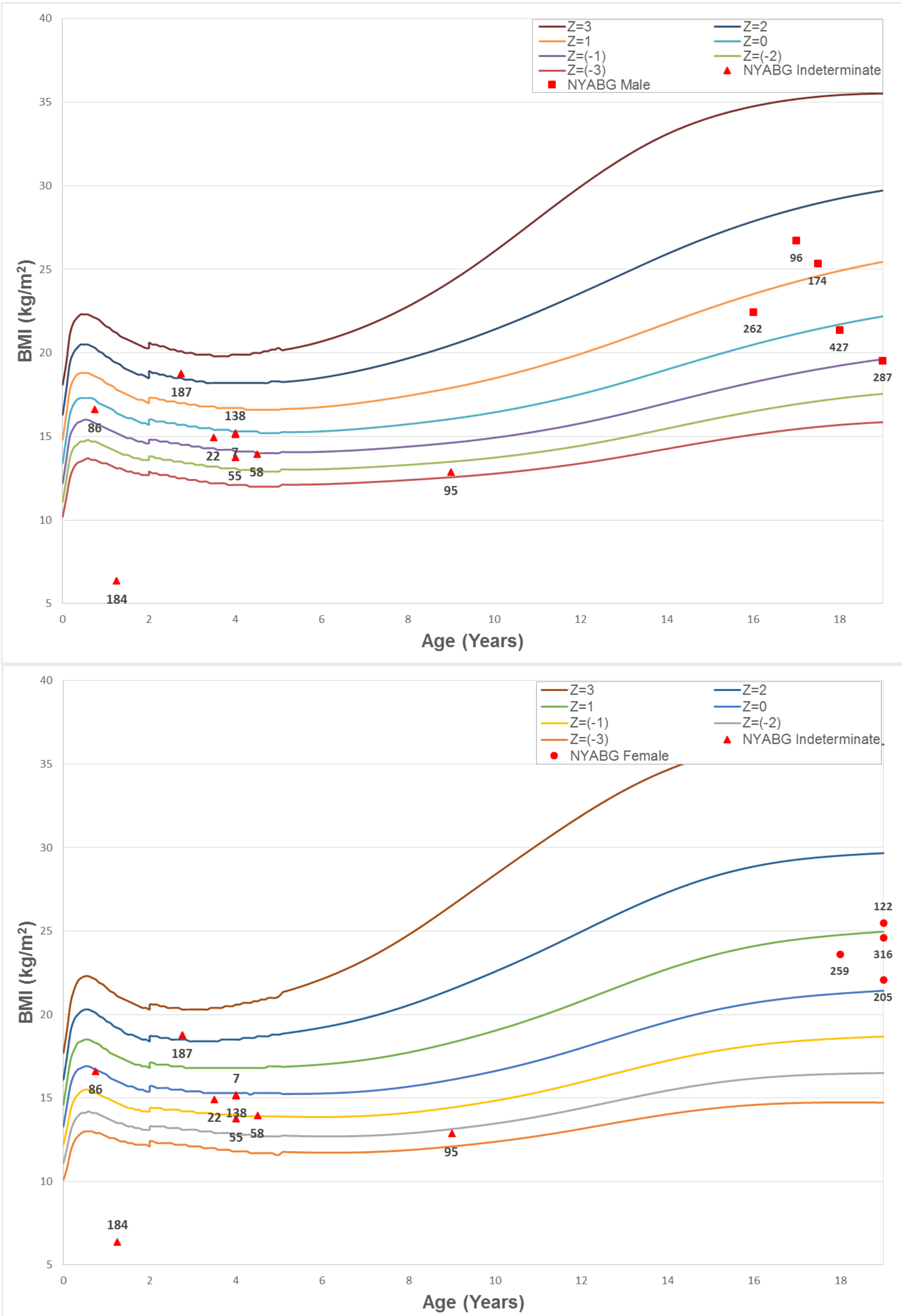

Fig. 19. New York African Burial Ground subadult body mass index estimates charted against international BMI-for-age z-scores from the 2006 World Health Organization (WHO) Child Growth Standards (birth to five years) and the 2007 WHO Growth Reference (five to 19 years) for males (top) and females (bottom). Individuals are labelled by NYABG burial number.

TABLE 16. Nutritional status in the New York African Burial Ground subadult sample by burial

Burial	Age (years)	Sex[a]	Weight-for-Age (%)	Height-for-Age (%)	BMI-for-Age (z-score, SD)	Nutritional Status[c]
86	0.75	I	0.1 – 3	<0.1	(-1,0)	Severely Stunted
184	1.25	I	<0.1	50 – 75	< -3	Severely Wasted
187	2.75	I	<0.1	<0.1	> 2	Severely Stunted
22	3.5	I	1 – 3	0.1 – 1	(-1,0)	Stunted
7	4	I	1 – 3	0.1 – 1	< 0	Stunted
55	4	I	0.1 – 1	0.1 – 1	(-2,-1)	Stunted
138	4	I	25 – 50	~25	< 0	Normal
58	4.5	I	5 – 10	5 – 10	-1	Normal
95	9	I	<0.1	0.1 – 1	(-3,-2)	Stunted and Wasted
262	16	M	–[b]	15 – 25	(0,1)	Normal
96	17	M	–	~0.1	(1,2)	Stunted
174	17.5	M	–	10 – 15	> 1	Normal
427	18	M	–	5 – 10	0	Normal
287	19	M	–	~15	-1	Normal
259	18	F	–	25 – 50	(0,1)	Normal
122	19	F	–	~15	> 1	Normal
205	19	F	–	~15	> 0	Normal
316	19	F	–	~10	< 1	Normal

[a] I = indeterminate sex, M = male, F = female.
[b] Weight-for-age percentiles for ages 10 to 19 were omitted from the 2007 WHO Growth Reference due to the variability of weight during the adolescent growth spurt.
[c] Stunted = Height-for-age ≤ 5%, BMI > -2 SD; Wasted = Height-for-age > 5%, BMI ≤ -2 SD.

CHAPTER VI.
DISCUSSION

Body mass estimation yields novel interpretations of robusticity and nutritional status for both the adult and subadult populations from the New York African Burial Ground (NYABG). Mean adult male and female body mass estimates for the NYABG sample were found to be statistically lower than mean adult male and female body weight from the 1960-1962 National Health Examination Survey (NHES) dataset. Although both sexes showed significant deficits in body mass, a greater proportion of NYABG adult males (94%) fell beneath the NHES median for body weight per age cohort than their female counterparts (56%).

This finding corroborates Goode-Null *et al.'s* (2009) interpretation that adult males showed greater deficits in stature than females. However, Goode-Null *et al*.'s (2009) assertion that adult females were therefore healthier than their male counterparts cannot be supported by the present analysis. Males are known to be less buffered than females against unfavorable nutritional conditions in pre- and postnatal environments (Stinson 1985). Furthermore, health status related to body size cannot be confidently assessed without considering whether the sample demonstrates low body mass as a result of low height, or low body mass per unit height, namely, body mass index (BMI).

While adult males and females showed significant deficits in body mass and stature compared to national anthropometric reference data, BMI estimates fell unanimously within or above the normal range. This negates current nutritional stress in the adult sample at time of death (WHO 1995). On the other hand, given the ubiquitous evidence of strenuous labor in both adult males and females from the New York African Burial Ground (Wilczak *et al.* 2009), it is unlikely that individuals whose BMI estimates exceeded the World Health Organization cut-off for overweight demonstrated sufficiently high percent body fat to warrant a health risk. As an index of weight per unit height, BMI cannot discern the ratio of lean body mass to fat mass (Nishida 2004; Ruff 2002; WHO 1995). Yet, additional evidence from widespread biomechanical stress markers in the NYABG adult population (Wilczak *et al.* 2009) supports an interpretation of high lean body mass represented by high BMI.

High frequencies of musculoskeletal stress markers (MSMs) and osteoarthritis suggest that both adult males and females had robust lower limbs, including a robust femur, yielding appropriately high BMI estimates for high muscle volume. The linea aspera and gluteus maximus insertion on the proximal femur ranked within the top sixth most frequent sites of hypertrophy for both sexes (Wilczak *et al.* 2009). Figure 20 exemplifies hypertrophy of the linea asperae in the femora of a NYABG female aged 45 years, whose BMI estimate (26.6 kg/m^2) exceeded the WHO cut-off for overweight[2]. The robusticity of the femoral head in addition to robust insertions indicating extremely well-developed muscles support an interpretation of extreme muscle mass and an appropriately high BMI estimate.

A greater proportion of the NYABG adult female sample fell within the normal range, however the sex difference in BMI did not rise to the level of significance. This is consistent with Wilczak *et al.*'s (2009) finding of few differences in skeletal hypertrophy and osteoarthritis among NYABG adult male and female samples. Both sexes showed high frequencies of musculoskeletal stress markers (MSMs) in regions of the skeleton associated with heavy lifting and carrying (Wilczak *et al.* 2009). Slight sex differences in the ranking of most frequent musculoskeletal stress markers may, however, suggest minor differences in the types of labor performed by males and females (Wilczak *et al.* 2009). Historians have shown that while

[2]This individual was not an outlier for either absolute body mass or BMI, and therefore serves as a representative example of the females whose BMI estimates fell within the overweight range.

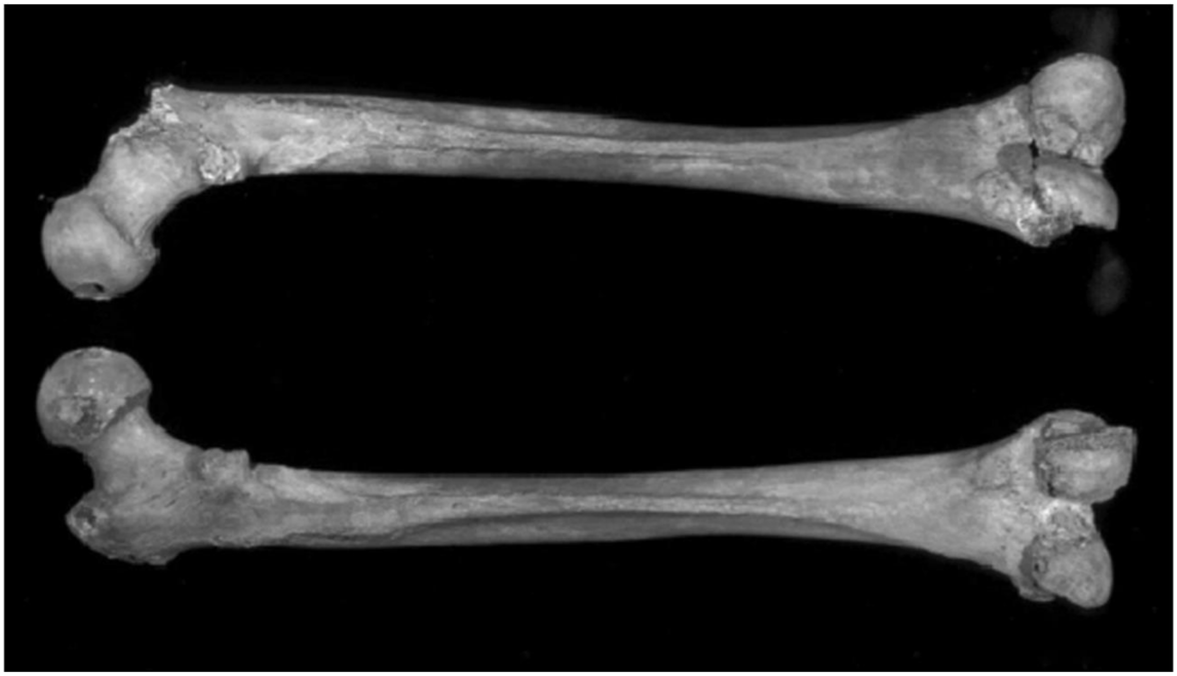

Fig. 20. Linea asperae hypertrophy in the femora of Burial 328, a female aged at 45 years with a BMI estimate of 26.6 kg/m^2, exemplifies extreme muscular robusticity in the adult sample. Photo courtesy of Wilczak *et al.* (2009).

divisions of labor existed between the sexes, both male and female New York Africans were held to the same high standards of physical labor in the 18th century, whether through domestic, commercial, or agricultural tasks (Davis 1984; Medford 2009). Insignificant differences in mean BMI estimates between the NYABG adult male and female samples may also correspond with minor differences in nutrition, perhaps as a result of employment in separate households (Davis 1984). However, differences in the degree of strenuous and labor and nutrition among the sexes were not supported with statistical significance by the present analysis.

Growth in body size among the children and adolescents of the New York African Burial Ground provides insight into life history and population growth overall. The NYABG subadult sample fell significantly below the 2006 WHO Child Growth Standards/2007 WHO Growth Reference median body mass per age cohort from birth to 10 years. Unlike adults, subadult BMI estimates showed evidence of current nutritional stress at the time of death. Several individuals in the subadult sample exhibited stunting below 18 years of age and wasting below 10 years of age. The observation of stunting or wasting in all individuals below four years of age suggests a prevalence of poor nutrition and/or disease during the postnatal period. This supports evidence of high infant mortality from the paleodemographic profile of the New York African Burial Ground and from historical data (Medford 2009; Rankin-Hill *et al.* 2009; Steckel 1987). However, the effects of poor health and nutrition during infancy persisted for several individuals throughout childhood and adolescence. Burial 95, age 9, was the only individual who exhibited combined stunting and wasting, likely indicating prolonged protein-energy malnutrition (Norgan *et al.* 2012). This malnourished individual may have also been unusually susceptible to disease as a result of a lowered host resistance, or at higher risk of malnutrition as a result of chronic disease (Goodman *et al.* 1984; Temple and Goodman 2014). Although the growth status of this child was likely unrepresentative of its surviving age and sex cohort, it provides an example of extreme and sustained unfavorable living conditions.

The observation that none of the NYABG male and female individuals between the ages of 17.5 and 19 showed stunting or wasting relative to the 2006 WHO Growth/2007 WHO Growth Reference supports the known potential for catch-up growth among American slaves. A historical analysis of anthropometric data from slave trade ship manifests collected from 1807 to 1864 demonstrated substantial catch-up growth among African slaves imported to the United States (Steckel 1987). Whereas the mean heights of African slave children fell below the first percentile of modern height standards, older male and female adolescents exhibited rapid catch-up growth to reach the 25^{th} and 30^{th} modern height percentiles, respectively (Steckel 1987). Although African slave children began to labor between six and 12 years of age (Medford 2009), this coincided with the provisioning of their diets with meat and perhaps other more nutritious foods (Steckel 1987). This is supported by the normal range BMI estimates reached among the NYABG sample in young adulthood.

The interpretation of catch-up growth within this population assumes homogeneous childhood origin. Yet, this was almost certainly not the case for the population interred at the New York African Burial Ground. Isotopic analyses of teeth from the New York African Burial Ground suggest that most subadult individuals in the skeletal sample lived in Manhattan their entire lives, while most older individuals with cranially modified teeth spent their childhood in Africa (Goodman *et al.* 2009). The normal to overweight range BMI distribution of the New York African Burial Ground adult sample relative to the low weight condition of some subadults could illustrate the effects of catch-up growth. However, it may also reflect the difference in living conditions experienced by those born in New York or the West Indies and those born in Africa.

There are several fundamental assumptions and limitations that caution these interpretations. The comparison of body mass estimates from the skeletal remains of the 18th century New York African Burial Ground population with anthropometric data from a nearly modern American population (the 1960-1962 National Health Examination Survey) assumes negligible change in mean American body size over time. However, it is well known that human body size has been increasing for at least 150 years, or approximately six generations (Cole 2003). Human biologists have rationalized that rapid growth in infancy as a result of favorable post-natal environmental conditions is biologically constrained by adverse consequences of that early growth later in life (Cole 2003). As a result, populations of common ancestry require many generations of favorable living conditions to reach their genetic potential for adult stature (Cole 2003).

Jantz and Jantz (1999) studied secular change in long bone lengths of Americans by regressing skeletal metrics to year of birth between 1800 and 1970 from the Huntington and Terry collections, World War II casualties, and the Forensic Anthropology Data Bank. Lower limb bones—particularly the femur—were found to increase proportionally with stature for males and females of both European and African ancestry, while upper limb bones were relatively unaffected by changes in stature. The male secular trend in femur length was significantly stronger than the female trend for both populations, and both persisted from the mid-late 19th century to the 1970s.

Analyses of the 1959-2005 National Health Examination Survey (NHES) and the National Health and Nutrition Examination Survey (NHANES) have shown that the net positive trend in American slowed height slowed following World War II and has fallen substantially below that of European populations, but has persisted nevertheless (Komlos and Lauderdale 2007). In the second half of the 20th century, adult males of African ancestry showed the highest rate of increase in height (Komlos and Lauderdale 2007). African American male and female children also showed a greater positive secular trend in height than European American children, according to the 1942-2002 NHES and NHANES datasets (Komlos and Breitfelder 2008).

The trend for increasing body mass corresponds not only with a positive secular trend in height, but also with increasing adiposity related to a rise in obesity among adults and children within the last half century (Cole 2003; de Onis *et al.* 2007). American adult body weight and the percent of the population overweight increased significantly from 1960 to 1991 for both sexes of African and European descended populations, according to the NHES and NHANES

(Kuczmarski *et al.* 1994). Anthropometric data for American children and adolescents from the Fels Longitudinal Study suggest significant increases in BMI (Johnson *et al.* 2012a; Johnson *et al.* 2012b), waist circumference/height, and percent body fat from 1960-1999 (Sun *et al.* 2012).

The overall secular trend in American adult height and adiposity confounds the assessment of adult body size in the New York African Burial Ground population relative to modern standards. The significant differences in mean adult male and female body mass between the New York African Burial Ground sample and the 1960-1962 National Health Examination Survey sample certainly reflect the positive secular trend in adult body size. Considering absolute adult body size alone, it is unclear whether deficits related to unfavorable environments in early childhood among the New York African Burial Ground population exacerbate the effects of the secular trend. Furthermore, greater deficits in body mass and stature among the adult male sample from the New York African Burial Ground (Goode-Null *et al.* 2009) could simply represent increased male sensitivity to environmental conditions and, in turn, the secular trend (Jantz 1999; Stinson 1985). Finally, this analysis assumes that the secular change in femur length is proportional to secular change in stature (Jantz 1999). If femur length has in fact increased at a slower rate than stature, than the regression formulas for stature estimation from the human femur would underestimate stature.

Body mass index (BMI) standardizes weight for height and therefore negates the effects of secular change on stature and body mass. However, BMI is not sensitive to population variation in body composition and proportion (Ruff 2002). Body shape varies systematically with latitude in a geographical cline (Ruff 2002). The genetic basis for this pattern is derived from adaptive mechanisms of the deep past (Ruff 2002). For example, Eskimo populations have relatively shorter limb lengths and greater body breath, traits adaptive for arctic climates (Ruff *et al.* 2005;

Ruff 2002). These proportions skew the population mean BMI toward the World Health Organization classification of overweight (Ruff 2002). However, these populations do not have increased adiposity relative to U.S. standards (Ruff 2002). At the other extreme, some Asian populations have a lower mean BMI relative to non-Asian populations (Nishida 2004). AWHO expert committee convened in 2002 to address whether BMI and percent body fat values associated with health risks in these Asian populations fall below WHO cut-offs for overweight (Nishida 2004). Although the expert committee did not redefine standard WHO BMI cut-off points for Asian populations due to the extensive variability among these populations, they recognized the importance of evaluating BMI distributions and quantifying the range for which health risks become significant for each population (Nishida 2004).

These examples suggest that inter-population variation in body proportions, body composition—including lean body mass fraction and percentage body fat—and body fat distribution can have a profound effect on the reliability of BMI cut-offs for assessing nutritional status and health risks (Nishida 2004; Ruff 2002). The normal to overweight range BMI distribution of the New York African Burial Ground population is problematic in terms of body composition. High fat free mass, specifically high muscle mass as a result of strenuous labor, can have a similar effect on BMI, and, in fact, on skeletal shape, as high adiposity (Godde and Taylor 2011; Rietsch *et al.* 2013). However, skeletal robusticity and stress lesions cannot distinguish obesity from activity (Godde and Taylor 2011; Rietsch *et al.* 2013). Furthermore, population variation in body proportions could also have misrepresented BMI for this population. Analyses of isotopic signatures, mtDNA, and morphological traits in the skeletal remains from the New York African Burial Ground have traced their recent ancestry to many regions of West and Central Africa (Jackson *et al.* 2009). The heterogeneity of this population warrants caution when evaluating BMI in terms of nutritional status.

This uncertainty in assessing health risk reflects a central limitation in the analysis of archaeological assemblages of human skeletal remains presented by Wood *et al.* (1992) in *The Osteological Paradox*. This seminal text highlights several important assumptions commonly made in bioarchaeological analyses. First, it is impossible to authentically assess demography and disease risk in skeletal samples due to a principle of selective mortality (Wood *et al.* 1992). Skeletal populations, by definition, only include individuals who perished. Given the assumption that a majority of individuals died of natural causes, skeletal samples negate the heterogeneity of disease risk and health within each age and sex category by selecting for the individuals who demonstrate the greatest "frailty," or risk of disease (Wood *et al.* 1992). In the case of the New York African Burial Ground population, subadults who demonstrate the greatest deficits in stature and body mass as a result of nutritional or disease stress likely had the lowest host resistance (Fig. 5) to environmental and cultural stressors (Goodman *et al.* 1984; Goodman 1993; Temple and Goodman 2014). In other words, the population interred at the New York African Burial Ground may include a greater proportion of subadults with short stature and low body mass than the living population, by virtue of their increased risk of disease and death (Temple and Goodman 2014; Wood *et al.* 1992)

Second, interpretations of health must be based on aggregate-level statistics, even if experienced at the individual biological level (Wood *et al.* 1992). Wood *et al.* (1992) consider the situation in which acute onset of physiological stress may result in rapid death without causing any pathological effect on skeletal tissue. These individuals may be misidentified as healthy at the time of death, due to a perceived lack of physiological stress in the skeletal record

(Temple and Goodman 2014; Wood *et al.* 1992). This is particularly true with anthropometrics, because malnutrition secondary to malnourishment or disease must be severe and sustained to cause deceased bone robusticity and long bone stunting (Kuzawa 2007; Lejarraga 2012; Norgan *et al.* 2012).

Finally, anthropometric indicators of stress do not necessarily imply poor health (Temple and Goodman, 2014). Whereas wasting implies acute nutritional stress, stunting reflects experiences of chronic malnourishment during early growth that may not persist into late childhood or adulthood (Kuzawa 2007; Lejarraga 2012; WHO 1995). Growth stunting and deficits in adult stature may therefore provide evidence of survivorship, rather than mortality, in response to chronic physiological stress experienced in childhood. This suggests that stunted individuals without wasting may in fact demonstrate lower susceptibility to disease than others in their age and sex cohort (Wood *et al.* 1992). It is this evidence of resilience and survivorship that endures throughout all age cohorts of the NYABG population.

CHAPTER VII.
CONCLUSION

A decade of osteological research on the New York African Burial Ground culminated in the reconstruction of a population that suffered strenuous labor, disease, and periods of poor nutrition (Blakey and Rankin-Hill 2009; Medford 2009), yet also demonstrated remarkable survivorship and endurance. To that end, this thesis reexamines the nutritional status of the population interred at the NYABG using novel anthropometric indicators. Adult male and females body mass index estimates fell unanimously within the normal to overweight range, according to the World Health Organization international classification of nutritional status (Nishida 2004; WHO 1995; WHO 2015a). These body proportions reflect robust muscles related to high physical activity (Wilczak *et al.* 2009) and adequate nutrition, in spite of widespread osteological indicators of nutritional stress (Null *et al.* 2009) and deficits in achieved adult stature (Goode-Null *et al.* 2009).

Among the subadult sample, some individuals showed wasting in response to acute malnutrition at the time of death, while many others showed growth stunting related to past experiences of sustained physiological stress (Lejarraga 2012; WHO 1995) that persisted through adolescence. It is unclear whether older adolescents and adults were advantaged nutritionally as a result of a remarkable biological capacity for catch-up growth (Cameron 2012; Steckel 1987; Tanner 1981), improved diet with the onset of labor (Medford 2009; Steckel 1987), or simply the inhospitable conditions of birth and growth in 18th century Manhattan relative to a childhood of freedom in Africa (Berlin 2009; Foote 2004; Goodman *et al.* 2009).

Nevertheless, the results presented here that demonstrate sufficient nutrition and robust body proportions in the New York African Burial Ground adult sample—juxtaposed with the prevalence of past or present anthropometric, biomechanical, and pathological indicators of stress in all age cohorts—effectively change the narrative. These anthropometric indicators of stress and recovery serve as a powerful reminder of the plasticity, resilience, and strength of the human body. As future research brings new findings to light, I hope that this narrative will continue to prevail in the collective memory of this integral New York City colonial population.

The implications of this research extend beyond the New York African Burial Ground. This analysis has demonstrated that for archaeological populations, considerations of biomechanics and body composition are critically important for assessing body size and nutritional status at the time of death. Furthermore, given the significant effects of secular change on human height (Jantz 1999; Komlos and Lauderdale 2007), as well as the frequent lack of comparative contemporary samples, stature may be insufficient for assessments of the anthropometry and health of past populations. Standardizing estimates of body mass for estimates of stature enables the comparison of past populations to the modern international WHO classification for underweight, overweight, and obese, and therefore represents a powerful addition to the bioarchaeological toolset. Finally, the findings presented in this thesis would be greatly enriched by future investigations of bone mineral density, cortical bone growth, and cross-sectional geometry for a more precise assessment of body mass and body composition (Hummert 1983; Macintosh *et al.* 2013; Moore 2008; Moore and Schaefer 2011; Rantalainen *et al.* 2013).

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