5-1-2024

The Impact of Obesity in Estimating Age-At-Death: An Analysis of Senescence of Features on the Auricular Surface

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by

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Under the Direction of Frank L'Engle Williams, Ph.D.

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

in the College of Arts and Sciences

Georgia State University

Spring 2024

ABSTRACT

Forensic anthropologists are commonly tasked with constructing a biological profile when attempting to identify an individual based on skeletal remains. During this process, age estimation is commonly accomplished by scoring the auricular surface of the os coxae. However, extrinsic factors such as obesity can influence the morphology of skeletal elements such as the auricular surface. In a sample of 151 individuals from the Bass Skeletal Collection at the University of Tennessee-Knoxville, three age groups (30-49, 50-64, and 65-80) and both biological sexes were examined, and their sacroiliac joints scored, using the Buckberry & Chamberlain system. This research attempts to expand on previous literature which indicates that obese individuals are often overestimated with respect to age based on the scoring of the auricular surface. The implication is that body weight, when available, should be considered when estimating age-at-death using the auricular surface to improve the accuracy and completeness of the biological profile.

INDEX WORDS: Age-at-death estimation, Auricular surface, Obesity, Forensic anthropology

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DEDICATION

This thesis is dedicated to friends, family, and loved ones for their continued support and encouragement. To my mother and father, your advice and reassurances have been invaluable in this research. To my friends and loved ones, I am forever grateful for your continuous motivation. I dedicate this current study to each of you.

ACKNOWLEDGEMENTS

This thesis could not have been completed without the insight and advice from several individuals. To Dr. Frank Williams, I am forever grateful for your continuous advice and encouragement to further my research in an enthusiastic manner. I also would like to express my sincerest acknowledgements to Dr. Nicola Sharratt and Dr. Bethany Turner-Livermore for their comments and feedback during the completion of this thesis, from the beginning phases to the final defense. I would also like to thank Dr. Jeffrey Glover, for granting access to photography equipment to conduct this research. This current study would not have been possible without the guidance of these individuals, whose support has been invaluable throughout the entire process.

I would also like to express my sincerest gratitude to all other faculty members and colleagues in the Department of Anthropology at Georgia State University. The support and encouragement have allowed me to complete this study to my fullest ability, and I am truly grateful for this department and university.

I also express sincere appreciation to Dr. Dawnie Steadman and the University of Tennessee-Knoxville for the ability and privilege to use the William M. Bass Donated Skeletal Collection. Access to this collection allowed for a sufficient sample size to complete this research, for which I am truly grateful.

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LIST OF ABBREVIATIONS

*BMI: Body Mass Index

*T.O: Transverse Organization

*S.T.: Surface Texture

*Macro: Macroporosity

*Micro: Microporosity

*In: Inches

*P-adj: Adjusted p-value

1 INTRODUCTION

The process of estimating age-at-death is vital in the field of forensic anthropology. Determining an individual's biological age as accurately as possibly allows for the completion of the biological profile which is used to establish an identity in unidentified human remains. In order to estimate age from the skeleton, forensic anthropologists examine traits on both the cranium and post-cranium (Brooks and Suchey, 1990; Buckberry and Chamberlain, 2002; Kimmerle et al., 2008; Meindl and Lovejoy, 1985; Meinl et al., 2008). When examining the post-cranium for age-at-death estimation, traits on pelvis are widely used. For example, the auricular surface, also known as the sacroiliac joint, is a site of attachment for the ilium of the os coxae and the sacrum and has been the subject of various studies for age-at-death determination (Buckberry and Chamberlain, 2002; Mulhern and Jones, 2005; Osborne et al., 2004). In order to accurately estimate age-at-death of skeletal remains, investigators use a variety of methods. (Buckberry and Chamberlain, 2002; Lovejoy et al., 1985; Osborne et al., 2004). As the life cycle of an individual continues, the auricular surface experiences various morphological changes which have been argued to be indicators of biological age (Lovejoy et al., 1985; Osborne et al., 2004). However, both intrinsic and extrinsic factors have also been determined to affect the rate of morphological change in the auricular surface, including physical activity (Villotte et al., 2010), nutritional levels (Ilich and Kerstetter, 2000), and menopause (Lindsay, 1996; Rizzoli et al., 2014). In addition, body mass, and obesity has been argued to influence age estimation in pelvic elements such as the auricular surface due to weight-bearing responsibilities (Drew, 2010; Wescott and Drew, 2015). Increased weight on the surface can result in a more rapid rate of morphological change, thus influencing age-at-death estimation. This current study aims to further understand how determining age-at-death can be influenced by obese body mass index

(BMI) levels. In particular, this research attempts to determine if individuals exhibiting obese BMI levels at the time of death are underestimated, overestimated, or accurately estimated in terms of biological age compared to their healthy weight counterparts based on the amount of morphological change that is present. Although previous studies have examined the relationship between obesity and age-at-death estimation from auricular surface morphology, this study seeks to provide even further clarity. Further understanding of this relationship will advance the field of forensic anthropology and result in more accurate aging practices.

1.1 Body Mass Index

According to the World Health Organization, obesity can be defined as a buildup of excessive fat that gives rise to health risks. An individual can be considered obese based on body mass index, or BMI, which considers both weight and stature. To determine an individual's BMI level, body weight in kilograms is divided by the height in meters squared (CDC). Adults with a body mass index score <18.5 is classified as underweight, while a range between 18.5 to 24.9 is considered to the healthy weight. A BMI level Between 25.0 to 29.9 is considered to be overweight and a score of >30.0 is described as obese (CDC). As this current study is strictly concerned with obese and healthy weight BMI levels, individuals exhibiting overweight and underweight ranges were excluded from consideration.

1.2 Obesity Rates

As obesity rates rise across the United States, understanding the influence of increased body mass on the morphology of human skeletal remains is invaluable in the field of forensic anthropology. Since 1980, obesity rates have witnessed a significant increase worldwide in the, as nearly a third of the world's population is categorized as overweight or obese (Chooi et al., 2019). In the United States, rates of obesity have doubled in the same timespan (Baskin et al.,

2005). The rise in obesity in the last several decades is illustrated in Figure 1. Currently, over 30% of adults in the U.S., or individuals 20 years of age or older, are considered obese based on their body mass index level (Baskin et al., 2005). As a result, understanding how obesity can impact the human body, and the human skeleton, is vital.

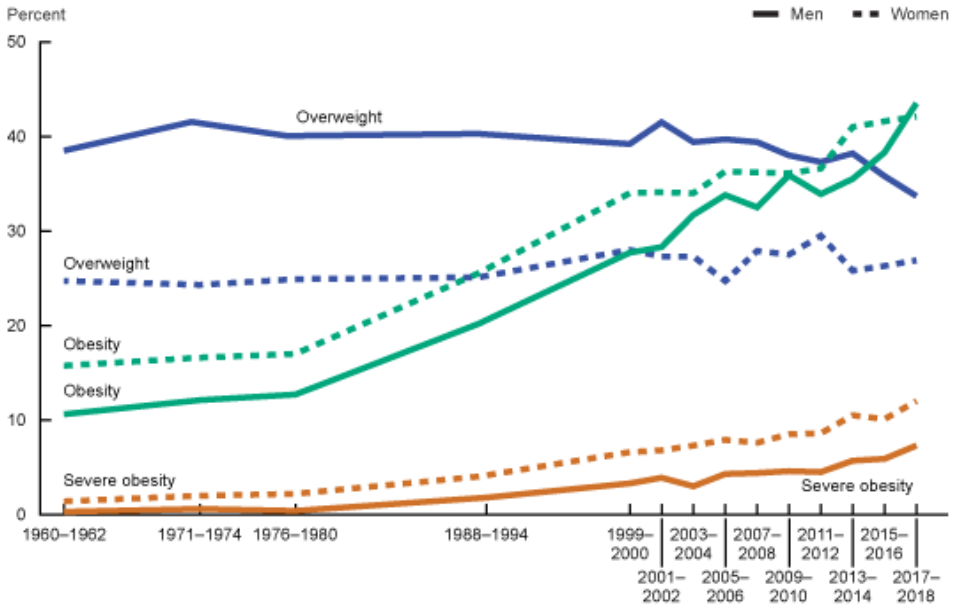

Figure 1: A graph illustrating rates of overweight, obesity, and severe obesity in adults aged 20 or older in the United States between 1960-2018 (CDC: Fryar et al., 2020)

1.3 Obesity and Bone Health

Individuals exhibiting obese body mass index levels have been shown to be more susceptible to potential risks to bone health than healthy weight counterparts. For example, obesity has been discovered to influence bone-regulating hormones, while also increasing inflammation and oxidative stress and modifying the metabolism of bone cells (Shapses et al., 2017). Recent studies have also determined that obese individuals experience decreased levels of bone quality, which can potentially result in an increased rate of fractures “for a given bone mineral density (BMD)” among obese individuals (Shapses et al., 2, 2017; Sukumar et al., 2011;

Nielson et al., 2011). Additionally, increased risk of fracture witnessed in obese individuals has recently caused concern that "metabolic complications" of obesity, including resistance to insulin, metabolic syndrome, and type 2 diabetes, may relate to poor bone health (Gower and Casazza, 450, 2013). Thus, changes in the morphology of the skeleton could potentially occu

1.4 Obesity's Influence on Load-Bearing Regions and Remodeling

Obesity also impacts load-bearing elements of the skeleton due to increase stress placed upon joints and joint surfaces. In particular, obesity has been discovered to influence locomotion and movement (Ko et al., 2010; Wescott and Drew, 2015). Individuals exhibiting obese body mass index levels have been found to walk at with slower gait speeds, wider width per step, and an increased rate of medial–lateral (ML) rotation in the hip (Ko et al., 2010; Spyropoulos et al., 1991). Compared to healthy weight counterparts, obese individuals also exhibit greater loading rates during locomotion (Pamukoff et al., 2016). Increased loading rates can potentially be a result of lesser knee flexion excursion which is significantly more common in individuals with increased body mass (Pamukoff et al., 2016). Previous studies have also determined that obesity can result in osteoarthritis in load-bearing elements such as the knee and hip (Anderson and Felson, 1988; Grazio and Balen, 2009**),** which can result in skeletal regions can result in decreased mobility function and poor extensor strength in the knee (Ling et al., 2003). In turn, obesity "predicts the development of mobility disability" due to the weight placed on the lower half of the body during gait (Ko et al., 1104, 2010). Thus, obesity is likely to influence the morphology of skeletal elements tasked with supporting body weight, such as the pelvis. However, age-at-death estimation is not strictly limited to weight-bearing regions of the skeleton. Forensic anthropologists are commonly tasked with analyzing both the cranium and post-cranium when determining biological age-at-death from skeletal remains.

1.5 Agenda

Chapter two of this study discusses the background of estimating age-at-death from the human skeleton, including a variety of traits that are commonly examined in forensic anthropology. In addition, I describe factors that influence skeletal morphology such as body mass among others. Chapter three focuses on age-at-death estimation from auricular surface morphology and various methods that have been introduced to accomplish this practice accurately and affectively. This chapter also highlights the influence of body mass and stature, the two components that comprise body mass index, on auricular surface morphology. I finish chapter three with a discussion on the hypothesis for this research. Chapter four discusses the methods employed in this study, while chapter five examines the results from a variety of statistical analysis. This study concludes with a discussion on how these findings relate to previous studies, as well as future steps and directions.

2 BACKGROUND

2.1 Methods for Estimating Age from the Skeleton

In osteological contexts, a variety of aging methods are utilized by anthropologists when estimating age-at-death. Each of these techniques examine different elements of the human skeleton that allow for unique age-at-death estimation. These often include cranial features such as ecto- and endocranial sutures and dental attrition as well as postcranial features including the auricular surface, ends of the sternal ribs, pubic symphysis, and state of osteoarthritis.

The auricular surface is one of the skeletal age indicators located on the pelvis. Estimating age from the auricular surface was popularized by Lovejoy et. al. (1985) through a series of age-intervals that an individual would be assigned based on visual assessment of several features. Recent studies, such as Buckberry and Chamberlain (2002) and Osborne et al. (2004), have attempted to revise the technique introduced by Lovejoy et al. (1985). The auricular surface has proven useful and reliable for estimating age in forensic contexts in part due to its ability to withstand taphonomic processes (Buikstra and Ubelaker, 1994; Osborne et al., 2004). As a result, aging the auricular surface is often available when fragmentary remains are present (Osborne et al., 2004). Analyzing the auricular surface for age estimation has produced accurate results in various studies (San Millán et al., 2013; Lovejoy et al., 1985, Hens and Belcastro, 2012; Hens et al., 2008).

The use of cranial sutures for estimating age in human remains has been discussed for nearly a century, with Todd and Lyon (1924, 1925) highlighting age-related patterns that occur in the closing of the sutures. The accuracy of age estimation using this skeletal element has been debated, with the technique receiving both praise and criticism. Meindl and Lovejoy (1985) performed studies using ectocranial suture closure from various sites across the cranial vault

which exhibited positive results. However, a wide array of studies has indicated the poor association of the method with actual age along with extensive variability (Hershkovitz et al., 1997; Milner and Boldson, 2012). Research has also been conducted on endocranial sutures, or junctions, that are located on the inside of the cranium. Various locations such as the endocranial sagittal suture, coronal suture, and lambdoid sutures, among many others, have been examined (Acsadi and Nemeskeri, 1970; Jangjetriew et al., 2007; Todd and Lyon, 1924). Although questions and criticisms still exist in using cranial sutures as a sole aging indicator, primarily around the accuracy and repeatability of the method, (Ruengdit, 2020; Todd and Lyon, 1924), endocranial sutures have been deemed to be more effective than those on the exterior vault of the cranium (Galera et al., 1998; Key et al., 1994). However, the inconsistencies between the methods highlight the need for a different cranial element to be inspected for its use in chronological age estimation.

Examining dental attrition is an additional method use by anthropologists to estimate age-at-death. Attrition, or wear, occurs as a result of direct contact between teeth as a result of mastication (Ball, 2002; Prince et al., 2008). To determine levels of dental attrition, both the occlusal and incisal surfaces are examined for the erosion of enamel (Ball, 2002; Faillace et al., 2017). The application of this cranial element for aging purposes became widespread in 1950 following Gustafson's (1950) method which analyzes six variables of the teeth (Ball, 2002). Several studies have modified the Gustafson (1950) method and are commonly used in forensic contexts for dental age-at-death estimation (Ball, 2002; Lamendin et al., 1992; Maples, 1978; Maples and Rice, 1997). Another attempt at age estimation using dental attrition involved an ordinal scoring system with six possible scores for incisors, seven for canines, and ten for premolars and molars (Faillace et al., 2017; Yun et al., 2007). In both methods, challenges arise

in scoring the dentition after eruption and functional occlusion are complete. Additionally, attrition is influenced through many extrinsic factors such as cultural, physical, sex, and individual variation (Lewis et al., 2021; Prince et al., 2008). These confounding variables reduce the internal validity of age-at-death estimation using dental attrition.

In addition to cranial features, the post-cranium also possesses several useful elements in determining chronological age of skeletal remains. One of these, the sternal end of the rib, has become more prominent in the aging process in recent decades (Dudar, 1993; Iscan et al., 1984; Yoder et al., 2001). In this method, numerical scores are commonly assigned to various rib components such as pit depth, pit shape, and rim and wall configurations indicating their individual ages (Iscan et al., 1994; Nikita, 2012). In various studies, the use of sternal rib aging has proven successful with high accuracy rates and limited inter-observer error (Dudar, 1993; Iscan and Loth, 1986; Nikita, 2012; Russell et al., 1993). However, this technique has been subject to recent criticisms (Fanton et al., 2010) and, although effective, requires improvements to remain reliable for future studies (Hartnett, 2010).

The pubic symphysis is another postcranial feature that is often evaluated to estimate age at time of death. This method has been used widely in forensic contexts for nearly a century. The method originally included a 10-phase scoring system based on morphological and degenerative changes that occur with age to various features of this skeletal element (Dudzik and Langley, 2014; Todd, 1921). Since the introduction of Todd's (1921) system, this technique of aging the pubic symphysis has undergone several improvements. Some methods have retained the use of phases to score the symphyseal face (Brooks and Suchey, 1990; Katz and Suchey, 1986), while others have implemented techniques that derive age estimates from the use of various stages (Dudzik and Langley, 2015; McKern and Stewart, 1957). Although these various

methods are utilized in examining the pubic symphysis, this post-cranial feature has widely been touted as one of the most accurate and reliable features in age-at-death estimation (Buikstra and Ubelaker, 1994; Dudzik and Langley, 2015; Sinha and Gupta, 1995).

Alongside permanent elements of the human skeleton such as rib ends and the pubic symphysis, patterns of osteological deterioration due to diseases such as osteoarthritis can also be useful when determining age-at-death from skeletal remains. Osteoarthritis can be impacted by various risk factors such as obesity and physical activity (Johnson and Hunter, 2014; Martel-Pelletier et al., 2016) but the disease is most commonly a result of aging (Loeser, 2017). Because the disease predominately affects older individuals, forensic anthropologists, in conjunction with other indicators, can more accurately estimate age-at-death if osteoarthritis is present. The disease can transition through various stages, with an increase in the severity of morphological changes as the condition progresses (Jurmain and Kilgore, 1995). For example, early stages, or slight involvement, of osteoarthritis are indicated by marginal osteophyte activity (Jurmain and Kilgore, 1995). Middle stages, or moderate involvement are marked by larger marginal osteophytes, while late stages, or severe involvement, are identified by large osteophytes and ankylosis and are sometimes accompanied by the presence of eburnation on the articular surfaces of long bones (Jurmain and Kilgore, 1995). In forensic cases, degenerative changes have typically been dismissed in terms of estimating age-at-death (Aykroyd et al., 1999). However, recent studies indicate that osteoarthritis, among other degenerative modifications, can be beneficial in determining chronological age in skeletal remains (Brennaman et al., 2017; Calce et al., 2018; Winburn and Stock, 2019).

Table 1: Elements examined for estimating age from the skeleton and respective methods that are commonly utilized in forensic contexts.

Aging Indicator	Description	Methods
Auricular Surface	Various morphological changes are examined through either visual assessment or composite scoring system. Activity is expected to increase with age.	• Buckberry and Chamberlain (2002) • Lovejoy et al. (1985) • Osborne et al. (2004)
Ectocranial Sutures	The degree to which sutures of the cranial vault are fused together or closed. Various ectocranial landmarks are examined for closure. The sutures continue to fuse together as age increases.	• Meindl and Lovejoy (1985) • Todd and Lyon (1925) • Sahni et al. (2005)
Endocranial Sutures	The degree to which sutures of the inside surface cranium are fused together or closed. Various endocranial sites are examined for closure. The sutures continue to fuse together as age increases.	• Acsadi and Nemeskeri (1970) • Baker (1984) • Todd and Lyon (1924)
Sternal End of the Fourth Rib	Various elements of the sternal end of the ribs are examined. Morphological changes occur and activity in this area increases with age.	• Hartnett (2010) • Iscan et al. (1984)
Dental Attrition	The degree of wear that exists on the occlusal and incisal surfaces because of contact between teeth from mastication.	• Gustafson (1947, 1950) • Lamendin et. al. (1992) • Li and Ji (1995) • Maples (1978) • Solheim (1993)
Pubic Symphysis	Examination of various morphological changes that occur as chronological age increases.	• Brooks and Suchey (1990) • Dudzik and Langley (2015) • McKern and Stewart (1957) • Todd (1921)

Aging Indicator	Description	Methods
Osteoarthritis	A degenerative disease that impacts joint tissues at the end of bones. Can result in morphological changes to the skeleton.	• Jurmain (1991) • Stewart (1958) • Watanabe and Terazawa (2006)

2.2 Factors Impacting Skeletal Aging

Estimating age of skeletal remains may also be made difficult by changes in skeletal biology due to external factors. Occupational stress including exercise and everyday activities impact the health of bone and can lead to skeletal remodeling or degeneration (Raggatt and Partridge, 2010; Wippert et al., 2017). Moderate physical activity has been shown to positively impact bone health, and it is crucial in maximizing the amount of bone mass gained in early life stages while reducing the degree of bone loss as an individual ages (Kohrt et al., 2004). In contrast, physical inactivity correlates with an increase in the risk of degenerative skeletal diseases such as osteoporosis (Carter and Hinton, 2014). Activity that involves tasks that place excessive strain on the skeleton and joints can result in enthesopathies, or stress-markers that appear on musculo-skeletal elements (Villotte et al., 2010). In addition, individuals participating in arduous manual tasks are noted to possess an increased number of lesions on their upper limbs compared to those who participate in "light manual" or "nonmanual" tasks. (Villotte et al., 224, 2010). Human variation in how the skeleton responds to strain makes assessing these physical stress markers difficult (Gualdi-Russo and Galletti, 2004) and is why age estimation is complicated by humans' participation in different levels and types of physical activity.

Challenges can arise in aging skeletal material due to diversity in nutrition levels, which severely impacts the structure and morphology of bone (Ilich and Kerstetter, 2000; Rizzoli,

2008). Bone reacts in varying manners depending on whether there is a surplus or deficiency of nutrition entering the body (Rizzoli, 2008). It has been shown that intake of specific nutritional factors such as calcium, protein, and dairy products are correlated to an increase in bone mass and overall bone growth (Ilich and Kerstetter, 2000; Rizzoli, 2008). Such nutrients are vital to the human diet, as the skeleton is regenerated around every 10 years to repair "microarchitectural damage" (Weaver, 413, 2017). This effort also aims to accommodate bone loss due to estrogen deficiencies that arise due to natural life processes such as aging and menopause (Weaver, 2017). Proper nutritional intake allows for the replacement of material that is lost in these life stages while also providing efficient various "growth demands" (Weaver, 413, 2017). Bone regeneration can be hindered by consuming a diet that lacks key nutritional values such as calcium and Vitamin D (Cashman, 2007; Institute of Medicine, 1997). Insufficient intake of these nutrients can also lead to an increased risk of skeletal diseases such as osteoporosis in later stages of life (Cashman, 2007). Variety in skeletal morphology is thus impacted not only by age-at-death, but also quantity and quality of nutrition throughout one's life.

Although activity and diet affect skeletal biology in both male and females, menopause critically impacts bone metabolism in individuals assigned female at birth. Menopause is a natural process that occurs in females generally beginning after 50 years of age and continuing for several years, culminating with the end of ovarian function and secretions (Greendale et al., 1999; Ouzounian and Christin-Maitre, 2005). Decreased estrogen levels result in bone loss, specifically in the endosteal component (Ahlborg et al., 2003). The rate of skeletal remodeling is increased as resorption rates exceed the rate of bone formation (Lindsay, 1996). Decreased levels of estrogen also result in the loss of the connection between formation and resorption, which is crucial in efficiently replacing resorbed bone (Dempster and Lindsay, 1993). Ultimately, bone

tissue is lost which increases the likelihood of potential fractures and possibility of osteoporosis. (Lindsay, 1996; Rizzoli et al., 2014). Additionally, while undergoing menopause, women lose roughly 60 mg of daily calcium in comparison to excreting only 20 mg prior to the process (Marcus, 2002). This combined loss of calcium and estrogen causes females to experience 2-3% of bone loss annually during the years immediately following menopause (Rizzoli et al., 2014). This number decreases to 0.5-1.0% thereafter (Rizzoli et al., 2014). Thus, bone loss and fragility that arise because of menopause can result in challenging age estimation.

The influence of body mass is another factor that can significantly impact the ability to estimate age-at-death of skeletal remains. For example, underweight individuals experience various changes in bone structure that can complicate skeletal aging. Low body weight is correlated with poor bone health due to low bone mass and higher risk for fractures (Espallargues et al., 2001, Shapses and Cifuentes, 2015; Shapses and Riedt 2006). Specifically in elderly individuals, low body weight can be a reliable predictor of both bone loss and degenerative diseases such as osteoporosis (Bakhireva et al., 2004; Ensrud et al., 2005). As a result, the effects on bone health from low quality nutrition can affect physiological age-related modifications (Coin et al., 2000). Analysis of low body weight in estimating chronological age in skeletal remains has typically been conducted on elements of the pelvis (Levin, 2020; Ronald 2022). In these studies, the age of underweight individuals has often been underestimated compared to their actual age at time of death (Merritt, 2015; Merritt, 2017; Ronald, 2022). However, certain studies have discovered the opposite, with skeletal remains from low weight individuals appearing older than the known age (Levin, 2020). The divergence in these findings highlights the challenges in age estimation due to external factors like body weight, nutrition, and physical activity levels.

Obesity is another extrinsic factor that can significantly impact the ability to estimate age-at-death of skeletal remains. Previous studies have indicated that obesity positively impacts bone and decreases the risk of degenerative diseases such as osteoporosis (Cao, 2011; Villarreal et al., 2005). It has also been reported that individuals with higher fat accumulation are more likely to experience deficiencies in vital micronutrients including Vitamin D which are important in retaining high levels of bone mass density across life stages (Bialo and Gordon, 2014). In forensic contexts, obesity has been reported to result in over- and underestimation of individuals when estimating age-at-death in traits such as morphological changes to the pubic symphysis and the auricular surface (Drew, 2010; Wescott and Drew, 2015). Compared to those exhibiting clinically normal body mass index levels, obese individuals produce results with higher rates of inaccuracy and a weaker relationship between estimated and known age (Wescott and Drew, 2015).

2.3 Body Mass Index in Osteological Studies

In recent years, body mass index, or BMI, has been problematized in various studies of osteological analysis. Primarily, levels of BMI, such as underweight, obese, and overweight, have been theorized to potentially influence the ability to age skeletal remains (Merritt, 2015; Merritt, 2017; Wescott and Drew, 2015; Ronald, 2022). For example, individuals with increased BMI levels have been overaged compared to known chronological age (Wescott and Drew, 2015). Obese individuals can experience accelerated aging in certain aging indicators, such as the auricular surface, due to increased stress on skeletal joint because of excessive body mass (Snijders et al., 1993; Wescott and Drew, 2015). Other studies have indicated that individuals with underweight levels of BMI can typically be underestimated compared to actual age-at-death due to a decelerated rate of aging (Merritt, 2015; Merritt, 2017; Merritt, 2020). However, other

analyses dispute these findings, and instead discover that individuals with underweight BMI levels are overaged (Levin, 2020) or no relationship between BMI and age is present (Ronald, 2022). In addition, body mass index has also been tested to determine its influence on degenerative skeletal diseases such as osteoarthritis which can indicate chronological age (Calce et al., 2018). Calce et al. (2018) discovered that body mass correlates with osteoarthritis development in pelvic joints but did not significantly affect other skeletal regions such as the lumbar spine or knee. As a result, age-estimation from pelvic aging indicators, such as the auricular surface and pubic symphysis, could be impacted by various levels of body mass index.

3 THEORY

3.1 Auricular Surface Aging and Life Cycle Changes

It has been hypothesized that as life stages progress and chronological age increases, morphological changes occur in skeletal joints such as the auricular surface. Particularly, the auricular surface has been discovered to experience degenerative modifications in its morphology as an individual transitions into later life cycles (Buckberry and Chamberlain, 2002; Lovejoy et al., 1985). Lovejoy et al. (1985) proposed five various life stages that can be applied to the auricular surface after morphological changes have been examined. These include the early post-epiphyseal phase, young adult phase, mid adult phase, early senescent phase, and breakdown (Lovejoy et al., 1985) (Table 2). As phases progress, the features of the auricular surface transition from unchanged to experiencing increased activity and into progressive destruction (Lovejoy et al., 1985). Although Buckberry and Chamberlain (2002) examined different variants of the auricular surface elements analyzed by Lovejoy et al. (1985), the more recent method produced similar findings to Lovejoy et al. (1985) in that morphological changes became more apparent as chronological age increased. However, it is important to further understand the methodology used by Lovejoy et al. (1985), Buckberry and Chamberlain (2002), and other studies on auricular surface aging to highlight the origin of this technique and how it has evolved over time.

Table 2: The stages of age progression as described in Lovejoy et. al. (1985).

Phase	Description
Early post-epiphyseal	An uneven, plate-like epiphysis becomes present and fuses quickly to the sacral portion of the sacroiliac joint after puberty has occurred. There is a lack of a similar epiphysis in the growth of the auricular portion of the joint. This phase typically occurs until the mid-20s.
Young adult phase	This phase stretched from the mid-20s to the mid-30s or slightly beyond; unchanging of the periauricular features; loss of billowing and an increase of a coarse granular texture.
Mid adult phase	Age changes in the surface become more apparent; features associated periauricular areas (such as the retroauricular area) are more pronounced and become useful in estimating age-at-death. This period stretches from the mid-30s to mid 40s.
Early senescent phase	This period occurs between the mid-40s and mid-50s. The surface becomes denser, and periauricular activity is enhanced. Alterations are mostly in grain, porosity, density, and the condition of the apex.
Breakdown	The subchondral bone of the surface experiences significant destruction. The severity of this process fluctuates between individuals, but in all cases, it involves elevated levels of porosity and irregularity, with pronounced periauricular changes.

3.2 History of Auricular Surface Aging

The auricular surface, defined as the area where the ilium articulates to the sacrum (Fig. 2), has been hypothesized to illustrate the process of aging due to morphological modifications that occur in this feature as chronological age increases. These transformations with age were first discussed by Sashin (1930), who noted that a relationship existed between the amount of fibrocartilage present in the joint and age. In the study, Sashin (1930) also reported that the iliac

cartilage becomes granular and roughened in individuals who have reached their fourth decade of life with osteophytes, or irregularities in the bone, around the margins. As aging continued in these individuals, ostephytosis with bony ankylosis became more apparent (Lovejoy et al., 1985). It is important to note that Sashin's (1930) senescent description of iliac cartilage does not directly relate to degenerative changes of the auricular surface, but the methods used in the study have been reported to be highly correlated (Lovejoy et al., 1985). Following Sashin (1930), various studies have examined morphological changes of the auricular surface to estimate chronological age. Three methods, Lovejoy et al. (1985), Osborne et al. (2004), and Buckberry and Chamberlain (2002), were vital in determining the effectiveness of this technique and its usefulness in forensic contexts. Lovejoy et al. (1985) and Osborne et al. (2004) utilized a phase method which involves visually analyzing a variety of morphological changes to the auricular surface simultaneously, and then designating an age-range based upon the features. Buckberry and Chamberlain (2002) implemented an ordinal scoring system that independently assigns a score to each characteristic observed. The scores of the features are then combined to establish an age range. As discussed below, both the phase method and the ordinal scoring system have proven to be useful methods in auricular surface aging.

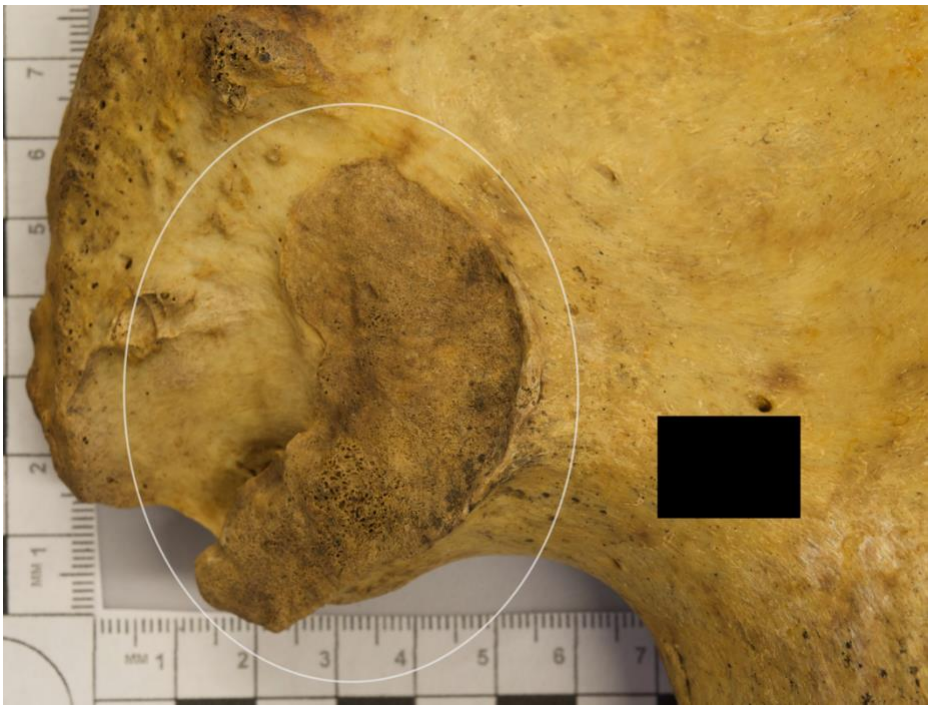

Figure 2: Auricular surface (circled); Scale = 1 cm. Black box is covering donor ID number.

In their research, Lovejoy et al. (1985) examined over 250 auricular surfaces from the Libbon population and roughly 500 individuals from the Hamann-Todd collection (Lovejoy et al., 1985). In addition, they analyzed fourteen forensic cases with known identification in each (Lovejoy et al., 1985). These initial analyses established a relationship between distinct characteristics of the auricular surface within these populations and senescence. The phase method was then performed to independently test two individuals from the Hamann-Todd collection who were unknown to the observers with sample sizes of 98 and 108, respectively (Lovejoy et al., 1985). The study examined seven characteristics that undergo morphological changes as age increases. These include grain and density of the surface, macroporosity, billowing, striations, or striae, apical modifications, activity in the retroauricular area, and transverse organization of the demifaces (Lovejoy et al., 1985). After these traits had been observed in specimens of the Hamann-Todd samples, one of eight phases was assigned, each

with a varying age range. Through tests of inter observer error and accuracy in predicating age at time of death, Lovejoy et al. (1985) determined their method to be repeated effectively. Thus, the technique was argued to be a valuable asset in age-at-death estimation (Lovejoy et al., 1985).

The Buckberry and Chamberlain (2002) method for estimating age-at-death from the auricular surface has been the subject of several recent studies. These conclude that the ordinal scoring-based system exhibits two advantages when applied in forensic contexts: durability from taphonomic conditions (Milner and Boldsen, 2012; Osborne, 2004) and high levels of replicability and accuracy among studies from multiple populations (Lovejoy et al. 1985, San Millán et al., 2012; Moraitis et al., 2013). Compared to other skeletal elements commonly examined in age-at-death estimation such as the pubic symphysis and the sternal rib ends, the auricular surface is often well-preserved despite various taphonomic process including carnivore activity (Haglund, 1997; Milner and Boldson, 2012, Osborne, 2000). In addition, the Buckberry and Chamberlain (2002) method is used among anthropologists on an international scale and thus assesses a variety of populations. For example, Millán et al. (2012) and Rissech et al. (2011) both utilized this method on samples of remains from Spain and determined the auricular surface technique exhibited more accurate results in comparison to the methods examining the pubic symphysis (Millán et al., 2012; Rissech et al., 2011). Additionally, the Buckberry and Chamberlain (2002) method also displays high levels of reliability in samples from other demographics, such as in Moraitis et al. (2013) who examined a modern European population. Although this method has been deemed useful and repeatable for estimating age in skeletal remains, improvements on the system have been suggested and discussed.

To prevent the potential overlap of narrow age ranges as witnessed from the Lovejoy et. al. (1985) method, the system introduced by Buckberry and Chamberlain (2002) significantly

broadened age ranges **(**Table 3). Although these ranges were substantially wider than Lovejoy et. al. (1985), the revised method of Buckberry and Chamberlain (2002) assigned a mean age, median age, and standard deviation for each range and composite score (Table 3). Tests on auricular surface aging have found that the wide age ranges of Buckberry and Chamberlain (2002) are more effective and applicable than previous techniques (Hens and Belcastro, 2012; Hens and Godde, 2022). The broad ranges can result in high levels of accuracy but devalue rates of precision (San Millán et al., 2013). Merritt (2013) determined that the 95% confidence intervals for revised aging methods such as Buckberry and Chamberlain (2002) are so broad that it "becomes almost impossible to incorrectly estimate the age of the individuals" (113). Thus, comparing estimated age to biological age by measures of central tendencies could potentially allow for more precise results. However, this is widely dependent on the sample that is being examined (Buckberry, 2015). In particular, the overall age distribution of a population can influence whether mean ages appear younger or older in between age groups (Buckberry, 2015). Buckberry (2015) also argued that unchanged mean ages should be avoided when estimating age unless the reference sample utilized to age an unknown individual possesses a similar age-at-death profile to the "population the unknown individual came from" (327). To avoid potential biases that exist in mean ages, Bayesian statistical analysis can be beneficial (Buckberry, 2015). Buckberry and Chamberlain (2002) introduced a composite scoring system for auricular surface aging; however, other contemporary studies, such as Osborne et al. (2004) have attempted to improve phase-based assignment techniques.

Although many studies exclusively follow the methods from either Lovejoy et al. (1985) or Buckberry and Chamberlain (2002), or a combination of both, recent analyses by Osborne (2000) and Osborne et al. (2004) have adapted the process of estimating age-at-death from the

auricular surface. These studies, both of which use identical samples of 266 combined individuals from the Bass Collection and Terry Collection, modify the method established by Lovejoy et al. (1985) by reducing the number of age-range phases. A reduction from eight phases to six is recommended, as the five-year intervals of age-ranges established by Lovejoy et al. (1985) are deemed to be insufficient in forensic contexts (Osborne, 2000; Osborne et al., 2004). It is also stated that the revised six-phase system allows for more "robust phase categories" and more accurately highlights the relationship between the morphological changes of the auricular surface and chronological age (Osborne et al., 6, 2004). Evaluation of the revised method, brought about by Osborne (2000) and Osborne et al. (2004), have exhibited results with mixed levels of success. Her (2021) and Miranker (2016) advocate for the use of this method in forensic settings and its high degree of accuracy. However, Herrera and Retamal (2017) question the reliability and applicability of the method in forensic settings due to "high scattering" and "overlapping" of various adjoining phases (317.e2).

3.3 The Influence of Body Mass and Stature on Auricular Surface Aging

An individual's body mass index, or BMI, can provide valuable information in forensic contexts. An individual's BMI level is calculated through a ratio of body weight at the time of death in kilograms to stature, or height, in meters squared (Wescott and Drew 2015). In various studies, body mass index levels have been reported to influence the ability to estimate chronological age from skeletal elements such as the auricular surface. Wescott and Drew (2015) analyzed the role of obesity on auricular surface aging from a sample of 226 skeletons from the William M. Bass Collection. In this study, individuals exhibiting clinically healthy or obese BMI levels were examined, and their age was estimated using the Buckberry and Chamberlain (2002) technique (Wescott and Drew, 2015). Wescott and Drew (2015) discovered higher levels of

inaccuracy in individuals among the obese BMI group than those with normal BMI levels, a conclusion also reflected in Drew (2010). However, individuals from both the obese and normal BMI ranges exhibited similar patterns for overestimation and underestimation between age groups (Wescott and Drew, 2015). Younger age groups were overestimated for chronological age while older age groups were commonly underestimated (Wescott and Drew, 2015).

Higher BMI levels can impact the morphology of the auricular surface due to obese individuals exhibiting increased amounts of stress on their joints compared to those in normal and underweight BMI groups (Browning and Kram, 2007; Wescott and Drew, 2015). As a result, degenerative changes to the auricular surface can occur at an accelerated rate in these individuals (Wescott and Drew, 2015).

Using a combined sample of 746 skeletons from the Hamann-Todd and William Bass Collections, Merritt (2017) also examined the impact of body mass index levels on estimating age from the auricular surface. Merritt (2017) employed methods from both Buckberry and Chamberlain (2002) and Lovejoy et al. (1985) and compared their age estimations for the sample population. The study discovered that individuals from the underweight BMI group were more accurately scored by the Buckberry and Chamberlain (2002) method than Lovejoy et al. (1985). However, chronological age was still overestimated by three years (Merritt 2017). The study also deemed the Buckberry and Chamberlain (2002) method to be inefficient for aging individuals with obese BMI levels due to consistent over-aging. However, methods from Lovejoy et al. (1985) were determined to be reliable across all BMI groups with consistent bias scores unlike the Buckberry and Chamberlain (2002) method (Merritt, 2017). Merritt (2015) found that bias scores are not affected by BMI using the Lovejoy et al. (1985) method.

According to both Wescott and Drew (2015) and Merritt (2017), body mass and BMI are factors that should be considered when estimating age-at-death from the auricular surface. Understanding the influence BMI levels can have on morphological changes of the auricular surface can result in more accurate age estimates in forensic settings.

3.4 Hypothesis

Based on previous research, it is possible to hypothesize results between age groups, sexes, and BMI distinctions in the current study. Several analyses on estimating age-at-death using the Buckberry and Chamberlain (2002) method for the auricular surface have indicated that older individuals are typically underestimated, while younger individuals are overestimated (Her, 2021; Ost, 2022). Rissech et al. (2011) determined that the Buckberry and Chamberlain (2002) scoring method did not exhibit inaccurate results in individuals under 53 years of age and were most inaccurate between the ages of 53-92. However, when evaluating the influence of body mass index on age estimations, results show varying relationships. Merritt (2017) determined that the Buckberry and Chamberlain (2002) scoring system exhibited no significant differences in accuracy scores for any age cohort examined in the study which were 19-49, 50-59, 60-69, and 70-79 (Merritt 2017). However, in a study on the effects of obesity on auricular surface aging, Wescott and Drew (2015) found that younger individuals were typically overestimated, and older individuals underestimated, in both normal weight BMI and obese weight BMI samples. In the current study, I expect that individuals exhibiting obese body mass index levels will be overestimated compared to their counterparts with healthy BMI levels.

Studies on auricular surface aging using the Buckberry and Chamberlain (2002) method have also discovered contradictory results for age estimation across different sexes. In their analyses, Buckberry and Chamberlain (2002) determined that no significant difference existed

between males and females when scoring the features of the auricular surface. Similar sentiments were reflected in other studies such as Moraitis et al. (2013) and Mulhern and Jones (2005). However, other research has indicated that sexual differences are present (Hens and Belcastro, 2012; San Millán et al., 2013). Thus, while I expect to see differences in the rate of morphological changes between males and females, I hypothesize this variation will be insignificant for evaluating age at death using the Buckberry and Chamberlain (2002) method.

In various analyses, obesity has been determined to overestimate age-at-death from skeletal remains. For example, it has been found that individuals exhibiting obese BMI levels yield overestimated in ages (Merritt, 2017; Wescott and Drew, 2015) due to greater stress being placed on their joints during normal gait compared to healthy weight and underweight individuals (Browning and Kram, 2007; Wescott and Drew, 2015). This sentiment also applies to the auricular surface, as Wescott and Drew (2015) discovered that this can be transformed by increased body mass due to the joint's task of weight transfer via the auricular surface from the spine to the lower limbs. In addition, Merritt (2015) determined that underweight individuals experienced decelerated rates of aging compared to obese counterparts. These rationales would support the idea that biological age for individuals with obese BMI levels is more likely to be overestimated rather than underestimated.

4 METHODS

4.1 Buckberry and Chamberlain (2002) Aging Method

Although Lovejoy et al. (1985) popularized the use of the auricular surface in estimating age-at-death, several flaws existed in its methodology and criteria. Analysis of results obtained from using this method discovered that age was often overestimated in older individuals and underestimated in younger individuals (Bedford et al., 1993; Murray and Murray, 1991). Buckberry and Chamberlain (2002) speculated this is due to frequent overlap of the 5-year age intervals of Lovejoy et al. (1985). Because various characteristics of the auricular surface such as porosity, surface texture, and modifications in the margin progress independently of one another, it is difficult to summarize them into one phase. Ultimately, the Lovejoy et al. (1985) system was believed to oversimplify the morphological changes that occur in the auricular surface, and age-ranges of only 5 years were argued to be too narrow (Buckberry and Chamberlain, 2002).

To overcome the flaws present in the Lovejoy et al. (1985) method, Buckberry and Chamberlain (2002) proposed a component scoring system that would examine each element of the auricular surface independently. Five features were analyzed including transverse organization, surface texture, microporosity, macroporosity, and modifications to the apex (Buckberry and Chamberlain, 2002). Following examination, each trait would be designated a numerical score that coincided to “successive stages of degrees of expression” (Buckberry and Chamberlain, 232, 2002). A score was assigned from 1-5 for the level of transverse organization, 1-5 for surface texture as the auricular surface transitioned from granular to dense bone, 1-3 for the amount of microporosity present, 1-3 for the amount of macroporosity present, and 1-3 for changes in the apex ranging from no visible alterations to lipping and irregularity

(Buckberry and Chamberlain, 2002) (Table 4). Figures 3-12 illustrate examples of upper and lower end scores for each of the five traits that were analyzed for this study.

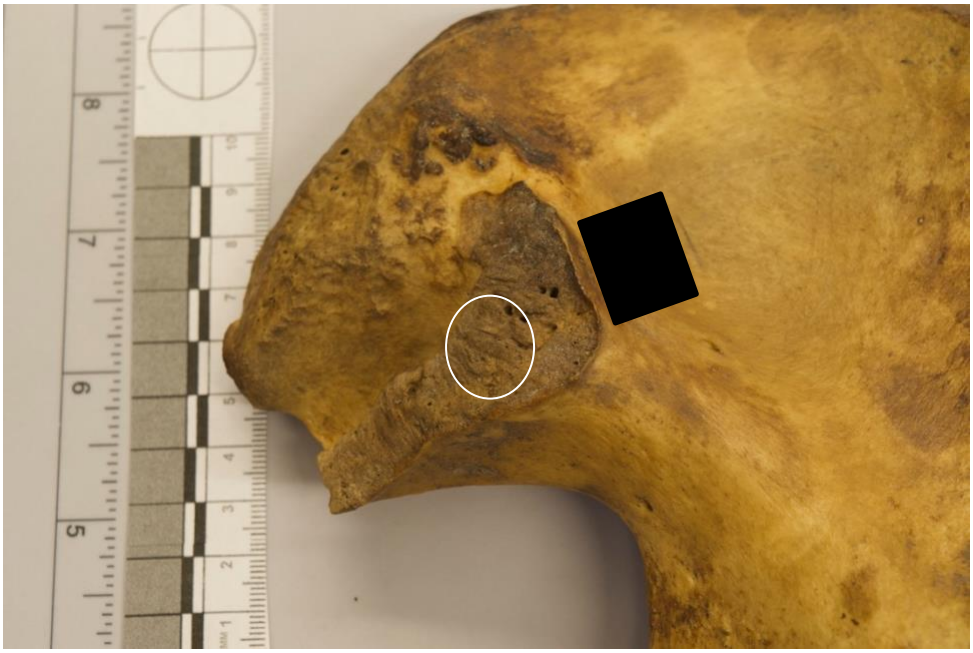

Figure 3: Example of a score of 1 or 2 for transverse organization based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

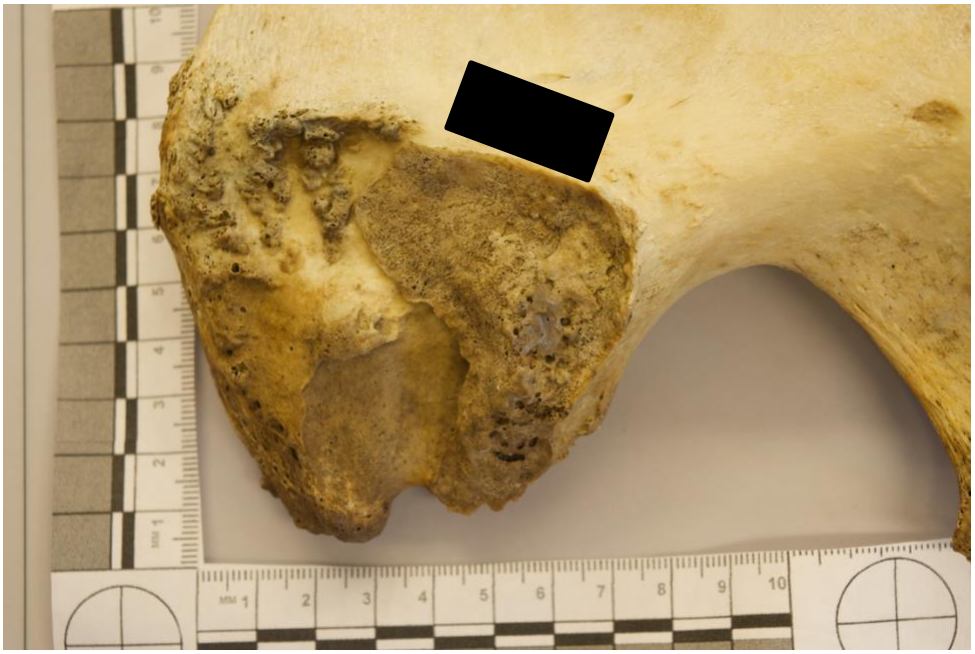

Figure 4: Example of a score of 5 for transverse organization based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

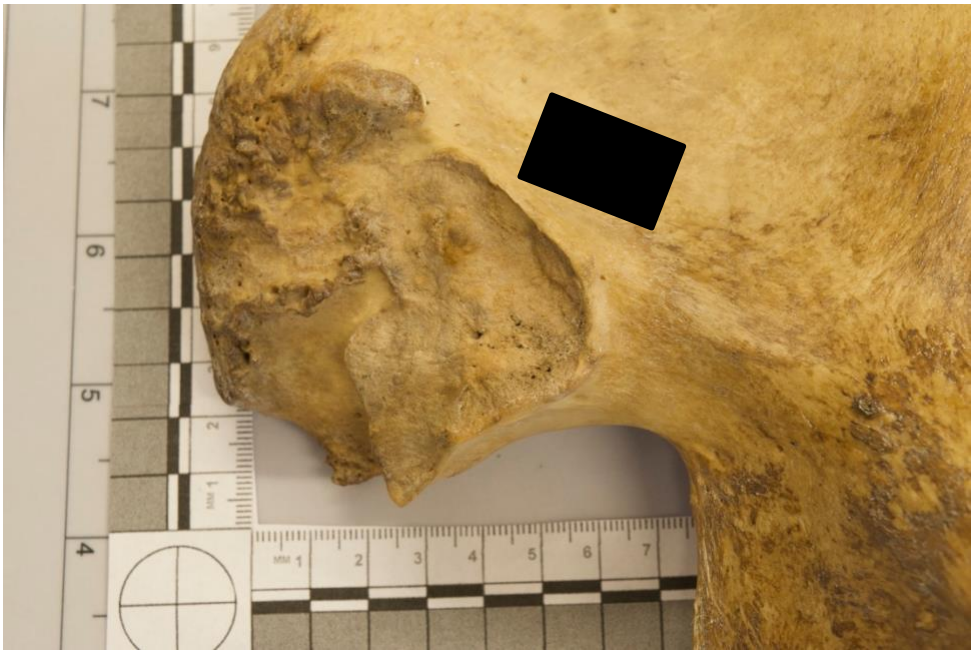

Figure 5: Example of a score of 1 or 2 for surface texture based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

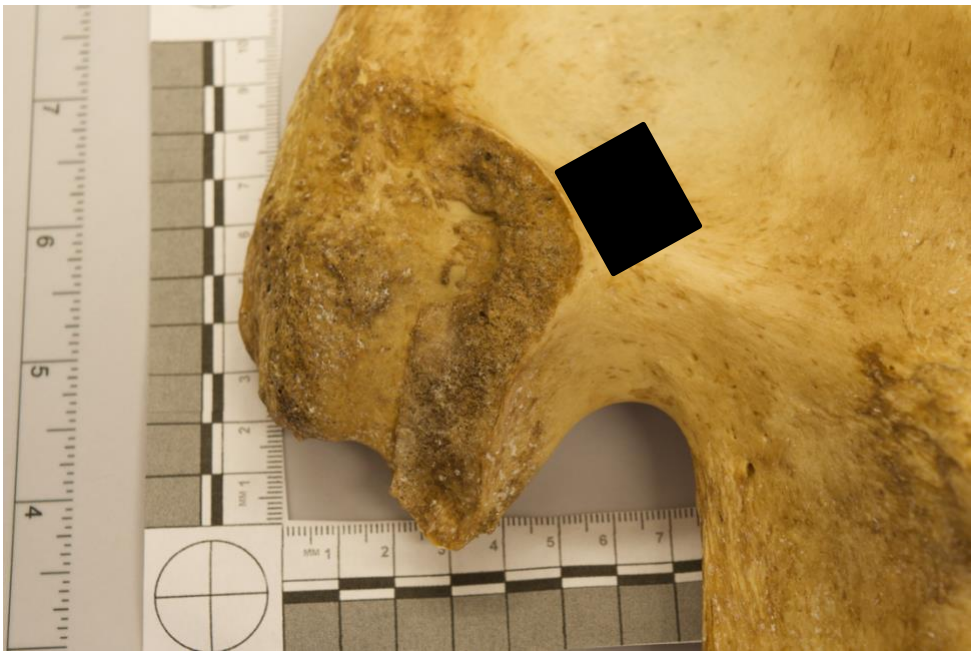

Figure 6: Example of a score of 4 or 5 for surface texture based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

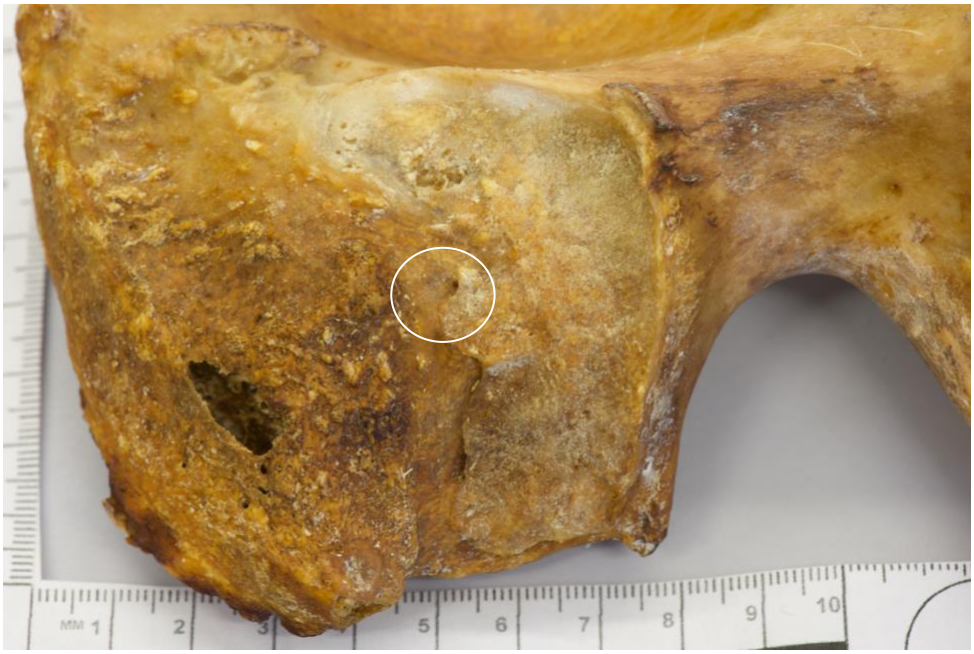

Figure 7: Example of a score of 1 or 2 for microporosity based on scoring criteria introduced by Buckberry and Chamberlain (2002).

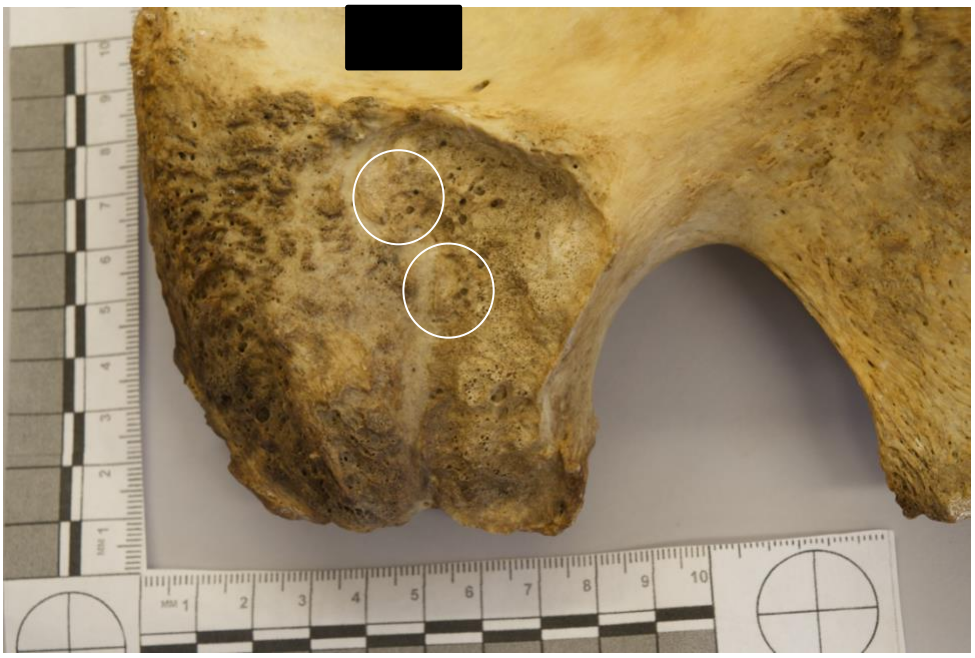

Figure 8: Example of a score of 3 for microporosity based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

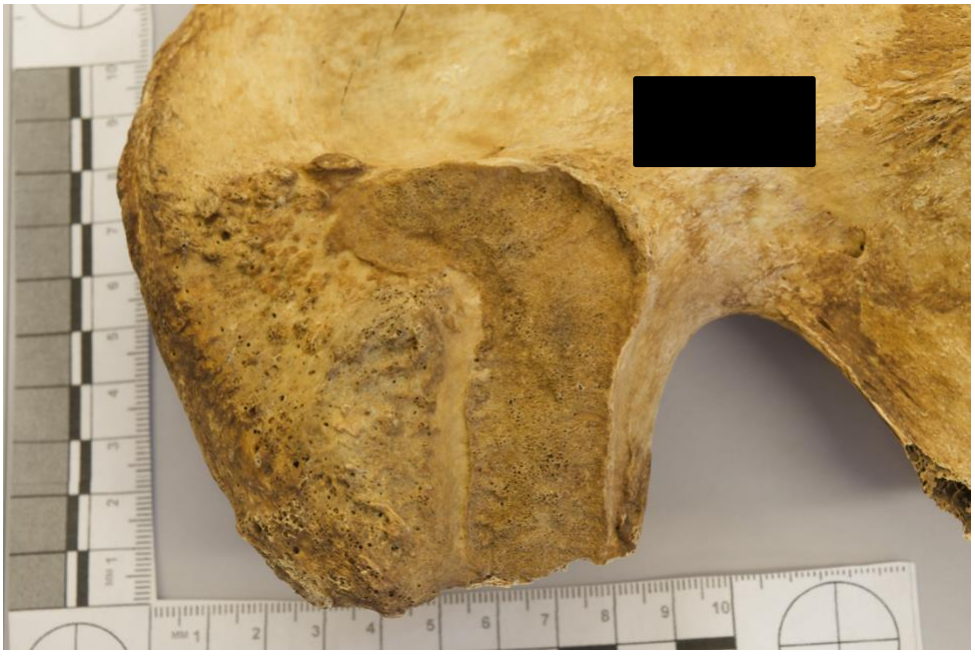

Figure 9: Example of a score of 1 for macroporosity based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

Figure 10: Example of a score of 3 for macroporosity based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

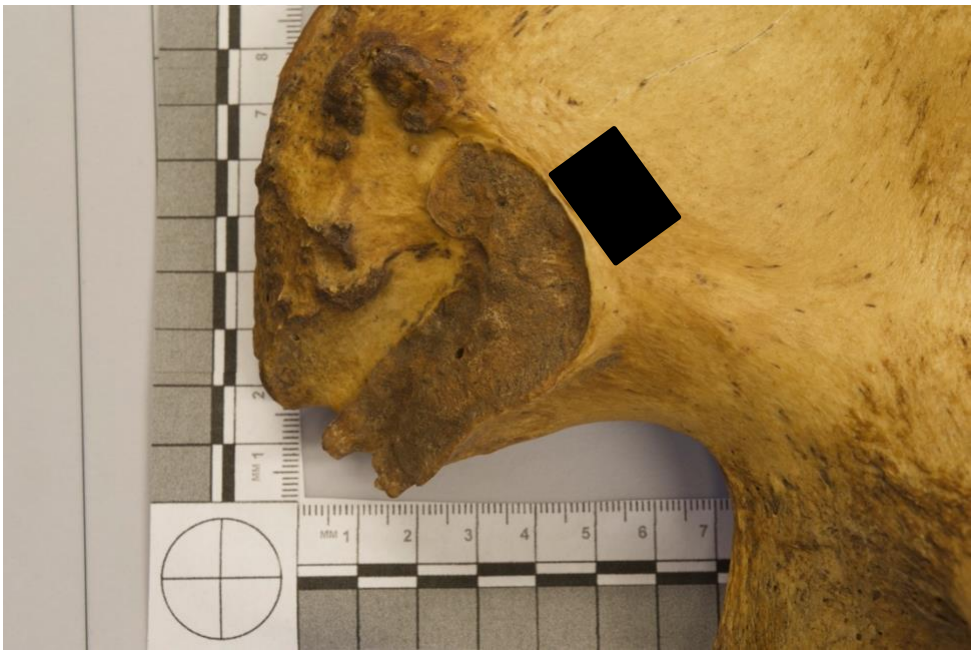

Figure 11: Example of a score of 1 for apical changes based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

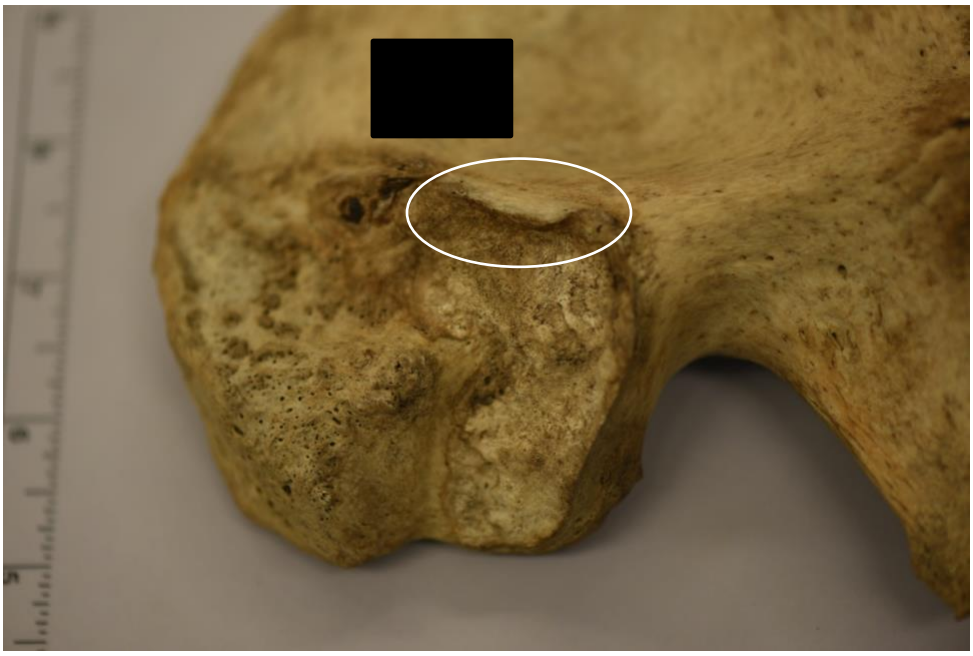

Figure 12: Example of a score of 3 for apical changes based on scoring criteria introduced by Buckberry and Chamberlain (2002). Black box is covering donor ID number.

After each score was collected, a composite score from the sum of all independent scores would be designated to an individual (Buckberry and Chamberlain, 2002). Seven composite ranges were developed by Buckberry and Chamberlain (2002): 5-6, or age stage I, 7-8, or age stage II, 9-10, or age stage III, 11-12, or age stage IV, 13-14, or age stage V, 15-16, or age stage VI, and 17-19, or age stage VII. Each composite score was also designated a mean range of chronological ages, along with median age and mean ages (Buckberry and Chamberlain, 2002). The scoring system is found in Table 3.

Table 3: Scoring system described by Buckberry and Chamberlain (2002) including composite scores, age stages, and age ranges.

Composite Score	Auricular Surface Stage	Mean Age	Standard Deviation	Median Age	Age Range
5-6	**I**	17.33	1.53	17	16-19

Composite Score	Auricular Surface Stage	Mean Age	Standard Deviation	Median Age	Age Range
7-8	**II**	29.33	6.71	27	21-38
9-10	**III**	37.86	13.08	37	16-65
11-12	**IV**	51.41	14.47	52	29-81
13-14	**V**	59.94	12.95	62	29-88
15-16	**VI**	66.71	11.88	66	39-91
17-19	**VII**	72.25	12.73	73	53-92

Table 4: The scoring system and descriptions for the traits examined by Buckberry and Chamberlain (2002) for estimating age from the auricular surface.

Features	Scores and Descriptions
Transverse Organization	**1**: At least 90% of the surface exhibits transverse organization **2**: Between 50–89% of the surface exhibits transverse organization **3**: Between 25–49% of the surface exhibits transverse organization **4**: Less than 25% of the surface exhibits transverse organization **5**: No transverse organization is present on the surface

Features	Scores and Descriptions
Surface Texture	**1**: At least 90% of the surface is characterized by a finely granular texture **2**: Between 50–89% of the surface is characterized by a finely granular texture; coarsely granular bone replaces finely granular bone in certain regions of the surface; dense bone is not apparent on the surface **3**: At least 50% or more of surface exhibits a coarsely granular texture, but dense bone is not apparent **4**: Dense bone is apparent, but is present on less than 50% of the surface; this may be just one small area of dense bone in very early stages of formation **5**: At least 50% or more of the surface is characterized by dense bone
Microporosity	**1**: No microporosity exists **2**: Microporosity exists on one demiface only 3: Microporosity exists on both demifaces
Macroporosity	**1**: No microporosity exists **2**: Macroporosity exists on one demiface only **3**: Macroporosity exists on both demifaces
Apical Changes	**1**: Apex is clearly defined and sharp; auricular surface may exhibit minimal elevation in comparison to surrounding bone surface **2**: The apex exhibits slight lipping, but shape of articular margin is still evident and smooth (shape of outline of surface at apex is an arc that is uninterrupted) **3**: Irregularity is present in the contours of the articular surface; shape of apex is no longer a smooth and continuous arc

In order to determine the effectiveness of this revised method, an age-masked test was conducted on a sample of 180 individuals from Christ Church, Spitalfields, London in which the age-at-death was known (Buckberry and Chamberlain, 2002). Two identical tests were administered, with a two-week duration separating the analyses (Buckberry and Chamberlain, 2002).

The study utilized various analytical and statistical tests to examine the results of the method. A stepwise multiple regression illustrated that all five of the elements that were scored contributed to the estimation of age (Buckberry and Chamberlain, 2002). A Spearman's correlation coefficient was also calculated to determine the relationship between each scored characteristic of the auricular surface and age (Buckberry and Chamberlain, 2002). All were deemed to be significant at the 99% confidence level (Buckberry and Chamberlain, 2002). In addition, a t-test was calculated to determine if any significant differences were apparent between males and females, for which none were found to exist (Buckberry and Chamberlain, 2002).

The Buckberry and Chamberlain (2002) system for scoring the auricular surface transitioned away from narrow age ranges and phase-based assignments to wider age ranges and composite scores. Although this revised method has proven to produce accurate age estimations, it is important to describe the techniques used from past and current studies on auricular surface aging to highlight how the Buckberry and Chamberlain (2002) system differs.

4.2 Differences Among Auricular Surface Aging Methods

Currently, two primary methods are typically utilized to determine age-at-death from the auricular surface: a phase-based assignment system and composite scoring. Designating phases

to the auricular surface for aging purposes originates from research conducted by Lovejoy et al. (1985), but the technique has since undergone revisions in a study by Osborne et al. (2004). To designate an individual into a phase, Lovejoy et al. (1985) examines a variety of features on the auricular surface and documents their morphological condition. These characteristics include grain and density, macroporosity, billowing, striations, apical changes, retroauricular area activity, and transverse organization (Lovejoy et al. 1985). Based on the combined state of these features of the auricular surface, the individual would be assigned one of eight phases, each with its own range of ages (Lovejoy et al. 1985) (Table 5). These age-range phases are then classified into four stages of aging developed by Lovejoy et al. (1985): the young adult phase, mid adult phase, early senescent phase, and breakdown (Table 2). Seemingly, as age-related changes modify the auricular surface, the individual would be placed in a higher phase and, thus, an older age-range. More recent studies, such as Osborne et al. (2004), have also utilized phases for estimating age in the auricular surface, but with modifications to the original Lovejoy et al. (1985).

Table 5: The phases designated to an individual based on the condition of auricular surface features as described in Lovejoy et. al. (1985). The study states that the age ranges are best characterized by these certain morphological changes.

Phase	**Age Range**	**Description**
1	20-24	Characterized by enhanced billowing and very fine granularity
2	25-29	Billowing is less marked, but the surface preserves a youthful appearance
3	30-34	Billowing is replaced by striae across the surface, and the texture transitions to coarsely granular

Phase	Age Range	Description
4	35-39	Coarse granularity is present across the entirety of the surface
5	40-44	Dense bone begins to replace coarse granularity; this process may occur on one or both demifaces
6	45-49	Uniform densification, granularity is no longer present
7	50-59	The surface is dense and uneven with rugged topography and slight to significant activity in periauricular regions
8	60+	Breakdown of the surface characterized by slight lipping, microporosity, enhanced irregularity, and significant activity in periauricular regions

Osborne et al. (2004) also employed a phase-based assignment system to age the auricular surface but with revisions to achieve more reliable results that are applicable to forensic contexts. Osborne et al. (2004) examined identical features to Lovejoy et al. (1985) but favored a combination scoring of all features rather than examining the factors independently. Their studies found a lack of significant differences among the mean ages of the eight phases used by Lovejoy et. al. (1985), and thus proposed the 5-year age ranges of Lovejoy et al. (1985) were too narrow for classification of individuals. As a result, Osborne et al. (2004) implemented a six-phase method for estimating age of the auricular surface (Table 6). According to Osborne et al.

(2004), the revised system of six-phases will allow for the "full range of variation of auricular surface morphology" to be presented and examined (6).

Table 6: The revised phase description of the auricular surface as described in Osborne et. al. (2004).

Phase	Morphological Features
1	Billowing is present with the possibility of striae; Finely granular
2	Striae are present; The texture is coarsely granular with slight areas of fine granularity
3	Striae are reduced, but present with transverse organization; The texture is coarsely granular; retroauricular activity is apparent; the apex is undergoing increased activity
4	Reduction of transverse organization; dense bone replaces coarse granularity; retroauricular activity is apparent; activity along the apex; macroporosity is marked
5	Surface becomes irregular and uneven; dense bone present; increase in retroauricular activity; increase in changes to the apex; macroporosity is prominent
6	Irregular surface; dense bone accompanied deterioration of the subchondral bone; uniform retroauricular activity; changes to the apex are significant; microporosity is prominent

4.3 Sample and Data Collection

This study seeks to further understand how estimating age-at-death from the auricular surface can be impacted by obesity based on an individual body mass index, or BMI, levels. Specifically, this research aims to discover if individuals with obese BMI levels were underestimated, overestimated, or accurately aged based on morphological changes of the

auricular surface. As a result, the current study also hopes to further prove or disprove previous research conducted by Wescott and Drew (2015) and Merritt (2017) regarding the relationship between obesity and age-at-death. To address this aim, the current study examined 151 donated skeletons with known age, sex, height, and weight at time of death from the William M. Bass Donated Skeletal Collection located at the University of Tennessee, Knoxville. The Bass Collection at the University of Tennessee, Knoxville was chosen for this study due to recent years of death and a sample that represents the living population and documented age-at-death and biological sex. Additionally, this collection is curated through donations with the consent of each individual. Thus, background information for each donation is known at the time of intake. This allowed for effective examination of the auricular surface without the interference of pathological and taphonomic conditions. The 151 individuals examined were separated evenly into three age range groups, consisting of solely adult skeletons. These included 50 individuals from 30-49 years of age, 52 individuals from 50-64 years of age, and 49 individuals from 65-80 years of age. Each age-range group represents a different life cycle stage, with young to middle-aged represented by the 30-49 year age range, middle to older-aged represented by the 50-64 year range, and older adults represented by the 65-80 year age range. The age for each individual in this study was known and documented at the time of examination. However, a blind study was conducted in which the age-at-death was not factored until examination of the auricular surface was complete. Ages between 30-80 were selected for various reasons. 30 years of age was chosen as the minimum age for this study to align with Buckberry and Chamberlain's stage II of the auricular surface and to allow to adequately determine if sexual dimorphism, as the sample size from stage I, or individuals typically under the age of 30, was deemed to be "too small" (Buckberry and Chamberlain, 235, 2002). A maximum of 80 years of age was selected to

encompass the highest mean age of 72.25 from the highest auricular surface stage from the Buckberry and Chamberlain (2002) criteria. A similar maximum age was also applied to a previous study on the relationship between obesity and age-at-death estimation from auricular surface morphology by Wescott and Drew (2015); however, the oldest individual in the sample from this study was 79 years of age. In order to determine if evidence of sexual dimorphism was present, the 151 individuals from this current study were divided into 74 biological males and 77 biological females. It is important to note that biological sex was self-assigned and documented, rather than estimated, for each individual. Although this trait was known before examination, I was unable to measure and quantify gender identity through approaches such as a 5-point Likert scale. Thus, the documented classification of biological "male" or "female" was utilized for this study. The breakdown of total individuals examined can be found in Tables 7-9.

Table 7: Individuals examined in this study sorted by the three age groups.

Age Group	Number of Individuals
30-49	50
50-64	52
65-80	49
Total	151

Table 8: Individuals examined in this study sorted by biological sex between each of the three age groups.

Biological Sex	30-49	50-64	65-80	Total
Male	25	25	24	74
Female	25	27	25	77

Table 9: Individuals examined in this study sorted by body mass level between each of the three age groups.

Body Mass Level	30-49	50-64	65-80	Total
Healthy Weight	25	25	27	77
Obese	25	27	22	74

The scope of each age range was specifically selected to avoid potential overlap of age estimation and to have the potential to establish significantly different mean ages. The minimum chronological age examined in the study was 30 years of age, while the maximum was 80 years of age.

4.4 Parameters for Body Mass Index Levels

As this study focuses on the effects of obese BMI levels on auricular surface aging, only individuals with either healthy weight BMI (between 18.5-24.9) or obese (>30.0) were examined and scored. A similar approach was employed in a study by Wescott and Drew (2005) on the influence of obesity on age estimation of the auricular surface where only individuals with a normal BMI (between 18.5-24.9) or obese BMI (>30.0) BMI were examined. With these respective BMI level criteria, individuals in this sample ranged from 90 pounds (40.82 kilograms) to 350 pounds (158.76 kilograms), and in terms of stature, individuals measured from 60 to 72 inches.

4.5 Age Estimation Method

To estimate age-at-death for individuals in this sample, the Buckberry and Chamberlain (2002) composite scoring system was employed. Each auricular surface examined was

designated a composite score consisting of the summation of each individual score assigned to the independent features as described in the Buckberry and Chamberlain (2002) system. The composite score assigned would then indicate the age-range of the individual, with each age group possessing a different mean age from another (Buckberry and Chamberlain, 2002).

4.6 Statistical Analysis and Methods

Several statistical tests were applied to the data to determine the accuracy of age-estimation of the auricular surface in individuals exhibiting either healthy weight or obese weight body mass index levels. All statistical analysis was completed using RStudio, and this program was also employed to construct the figures in this study. Linear regression was the primary form of analysis utilized in this research to determine the relationship between inaccuracy rates and body mass levels by examining the slope, r-squared value, and p-value. Both inaccuracy and bias were calculated between both body mass levels, three age groups, and biological sexes. This current study follows equations of inaccuracy and bias from research conducted by Wescott and Drew (2015). In age-at-death estimation, inaccuracy measures the numerical distance between the estimated age and actual age of an individual. In this study, estimated age was determined to be the mean age assigned to the total composite score from the Buckberry and Chamberlain (2002) scoring criteria. Inaccuracy is calculated as the mean absolute error, or MAE, and follows the equation: $\sum(|\text{estimated age} - \text{actual age}|)/\text{n}$ (Wescott and Drew, 2015). Inaccuracy is used to determine the difference between estimated age and actual age. Bias in age-estimation studies is used to determine if over- or underestimation has occurred between estimated age and actual age-at-death. Bias is calculated as the estimated age minus actual age divided by the size of the sample being examined $\sum(\text{estimated age} - \text{actual age})/\text{n}$ (Wescott and Drew, 2015). Pearson's correlation test was applied to inaccuracy rates to determine the correlation coefficient (r-value),

95 percent confidence interval, and p-value. T-tests were employed for both body mass levels for the three age groups and biological sexes to determine the mean values of inaccuracy, as well as to discover if a significant difference exists among the samples being compared. ANOVA, or analysis of variance, was computed to determine if significant differences occur across all three age groups and the biological sexes for both healthy and obese individuals. Following the ANOVA, a Tukey's Honest Significant Difference test was employed to determine which specific groups in comparison exhibit a significant difference. In addition to inaccuracy rates, statistical analysis was also applied to total composite scores assigned to each auricular surface based on the Buckberry and Chamberlain (2002) criteria. However, as this data are ranked, or non-continuous, non-parametric tests were implemented. To compare mean values across the three age groups and biological sexes, as well as determine if a significant difference exists, a Kruskal-Wallis test was employed between composite scores and body mass level. Several independent Mann-Whitney U tests were then conducted to discover which specific comparisons exhibit a significant difference. Ordinal logistic regression was employed on each of the five scoring traits from the Buckberry and Chamberlain (2002) criteria. Scatterplots were constructed which illustrate the probabilities at which these traits are to occur as chronological age increases. Higher probabilities of the maximum values of each of the five traits indicate greater practicality in age-at-death estimation.

4.7 Reworking of Buckberry and Chamberlain (2002) Statistical Results

In addition to further understanding the relationship between obesity and age-at-death estimation from auricular surface morphology, this current study also aims to classify individuals more accurately into an age range based upon the assigned composite score from the Buckberry and Chamberlain (2002) method. Previous research has indicated that the width of the age ranges

assigned to the composite scores for the Buckberry and Chamberlain (2002) method is a partial explanation for the high accuracy rates across various samples (Rissech et al., 2011). However, other studies have argued that wide age ranges are essential in order to account for morphological variation (Falys et al., 2006; Hens and Belcastro, 2012). However, in forensic anthropology casework, wide age ranges can result in difficulties assigning an identity to an unknown individual. As several of the Buckberry and Chamberlain (2002) stages exhibit wide age ranges from various periods of the life cycle, this current study seeks to reduce these ranges to assist in accurately assigning an age to missing persons or unidentified individuals. Similar data such as that in Table 3 was constructed for this current study based upon the original analysis performed by Buckberry and Chamberlain (2002). However, auricular surface stages in this current research were separated by one composite score rather than two as witnessed in the Buckberry and Chamberlain (2002) system in order to potentially reduce age ranges.

5 RESULTS

5.1 Inaccuracy and Bias

As previously discussed, both inaccuracy and bias were calculated for each of the three age groups, (Table 10) as well as between both biological sexes (Table 11) and body mass levels (Table 12).

Table 10: Inaccuracy and Bias values between age groups and body mass levels.

Age Group and Body Mass Level	Inaccuracy (Mean Absolute Error) in years	Bias
30-49 Healthy	7.770	4.304
30-49 Obese	12.038	11.296
30-49 Total	9.867	7.800
50-64 Healthy	6.634	0.835
50-64 Obese	4.337	1.759
50-64 Total	5.442	1.315
65-80 Healthy	10.841	-10.551
65-80 Obese	5.599	-5.038
65-80 Total	8.486	-8.076

Table 11: Inaccuracy and Bias values between biological sex and body mass level.

Biological Sex	Inaccuracy (Mean Absolute Error)	Bias
Males Healthy	6.787	0.799
Males Obese	7.575	6.044

Males Total	7.16	3.280
Females Healthy	9.808	-5.292
Females Obese	-7.147	-0.026
Females	8.426	-2.514

Table 12: Inaccuracy and Bias values for body mass levels.

Body Mass Level	Inaccuracy (Mean Absolute Error)	Bias
Healthy Weight	8.454	-2.031
Obese	7.314	2.695

Whereas inaccuracy determines how close the composite, or estimated, age is to the actual age-at-death, bias is used to measure if an underestimation or overestimation of known age has occurred. A positive inaccuracy value indicates the composite age was greater than the actual age, while a negative specifies the composite age was lower than actual age-at-death. Regarding bias, a positive value demonstrates that overestimation of age has occurred, while a negative indicates known age has been underestimated. As Table 10 illustrates, individuals from the 30-49 age group exhibits the most positive inaccuracy value (9.867), while the 65-80 group possesses the second-most positive (8.486), and the 50-64 with the least positive (5.442). Table 10 also shows the bias values between each of the three age groups. Similar to inaccuracy, individuals within the 30-49 age group exhibit the most positive bias value (7.80). However, the 50-64 age cohort possesses the second-most positive (1.315), and the 65-80 age group exhibits the only negative bias of the three age groups (-8.076). These results indicate that as biological age increases, underestimation of age-at-death is more likely to occur. In addition, between each of the age groups, the obese cohort exhibits greater bias values than the healthy weight counterparts

(Table 10). This further indicates that obese individuals are overestimated in terms of age-at-death than those exhibiting a healthy weight. Inaccuracy and bias values can be found for biological males and females in Table 11. Females were found to exhibit a greater rate of inaccuracy (8.426) compared to males (7.16). Regarding bias, males exhibit a positive value (3.280) while females possess a negative figure (-2.514). The bias values between males and females indicate that females are often underestimated in terms of age-at-death while males are typically overestimated. The values in Table 11 also reveal that the obese groups for both biological sexes exhibit greater bias value than their respective healthy weight cohorts, signifying that individuals with great body mass levels are overestimated for chronological age compared to those with a nonobese body mass level. Table 12 illustrates inaccuracy and bias values for both body mass levels. Healthy weight individuals exhibit a greater inaccuracy rate (8.454) compared to the obese cohort (7.314) but possess a lower bias value (-2.031) than the obese counterparts (2.695). These findings further indicate obese individuals are commonly overestimated in age-at-death estimation than those with a healthy weight.

5.2 Linear Regression and Pearson's Correlation

Linear regression and tests of regression analysis were conducted to determine the relationship between two or more variables. In particular, these analyses determine if multiple variables possess either a positive or negative relationship, or no correlation, with one another. Linear regression and regression analysis were used to calculate the r-squared values, or amount of variation present between the two values, the p-value, which determines if a significant difference exists, the slope, or beta coefficient, which is used to illustrate the strength of the relationship between variables, and standard error. For each linear regression, inaccuracy was compared with body mass index, with inaccuracy acting as the dependent variable and body

mass index as the independent variable. In addition, both the r-value, or correlation coefficient, as well as the 95 percent confidence interval around the r-value, were determined through a test of Pearson's correlation coefficient, which ranges from +1 to -1. The closer the r-value, or correlation coefficient is to +1, the stronger the relationship between the two variables. If the r-value is closer to -1, this indicates a negative linear relationship exists. A value of zero indicates that no linear relationship is present and that the variables are not correlated. The results from tests of linear regression, as well as the slope and correlation coefficient (r-value) for the relationship between inaccuracy and body mass index can be found in Tables 13-15. These statistical analyses were conducted between healthy weight and obese individuals, both biological sexes, and the three age groups examined in this study.

Table 13: Results from tests of linear regression and Pearson's correlation between body mass levels. Bold numbers represent a significant difference (<0.05).

BMI Level	Slope (beta coefficient)	Correlation Coefficient (r-value)	Standard Error	p-value	R-squared	95 percent confidence interval
Healthy	0.8993	0.158	8.87	0.336	0.025 (Multiple), -0.001 (Adjusted)	-0.167, 0.451
Obese	0.1511	0.075	8.355	0.669	0.005 (Multiple), -0.025 (Adjusted)	-0.265, 0.398
Healthy Weight & Obese (Combined)	0.375	0.307	8.54	**0.007**	0.094 (Multiple), 0.082 (Adjusted)	0.085, 0.501

Table 14: Results from tests of linear regression and Pearson's correlation between biological sex and body mass levels. Bold numbers represent a significant difference (<0.05).

Biological Sex & BMI Level	Slope (beta coefficient)	Correlation Coefficient (r-value)	Standard Error	p-value	R-squared	95 percent confidence interval
Females: Healthy Weight	1.446	0.245	10.29	0.138	0.060 (Multiple), 0.034 (Adjusted)	-0.081, 0.524
Females: Obese	0.296	0.170	9.36	0.302	0.029 (Multiple), 0.003 (Adjusted)	-0.154, 0.460
Females: Healthy Weight & Obese (Combined)	0.377	0.304	9.792	**0.007**	0.092 (Multiple), 0.080 (Adjusted)	0.086, 0.495
Males: Healthy Weight	0.8993	0.158	8.87	0.336	0.025 (Multiple), -0.001 (Adjusted)	-0.167, 0.451
Males: Obese	0.1511	0.075	8.355	0.669	0.005 (Multiple), -0.025 (Adjusted)	-0.265, 0.398
Males: Healthy Weight & Obese (Combined)	0.251	0.305	7.00	**0.008**	0.093 (Multiple), 0.080 (Adjusted)	0.082, 0.499

Table 15: Results from tests of linear regression and Pearson's correlation between age groups body mass levels. Bold numbers represent a significant difference (<0.05).

Age Group & BMI Level	Slope (beta coefficient)	Correlation Coefficient (r-value)	Standard Error	p-value	R-squared	95 percent confidence interval
30-49 Healthy Weight	0.157	0.028	9.024	0.895	0.0008 (Multiple), -0.043 (Adjusted)	-0.371, 0.418
30-49 Obese	-0.126	-0.091	8.015	0.666	0.008 (Multiple),	-0.469, 0.316

					-0.035 (Adjusted)	
30-49 Healthy Weight & Obese (Combined)	0.340	0.319	8.625	0.024	0.084 (Multiple), 0.102 (Adjusted)	0.044, 0.549
50-64 Healthy Weight	1.573	0.317	8.736	0.122	0.101 (Multiple), 0.062 (Adjusted)	-0.089, 0.633
50-64 Obese	-0.070	-0.060	5.870	0.768	0.004 (Multiple), -0.036 (Adjusted)	0.430, 0.328
50-64 Healthy Weight & Obese (Combined)	0.081	0.086	7.494	0.545	0.007 (Multiple), -0.012 (Adjusted)	-0.192, 0.351
65-80 Healthy Weight	-0.179	-0.182	1.530	0.364	0.033 (Multiple), -0.006 (Adjusted)	-0.526, 0.213
65-80 Obese	-0.261	-0.138	6.178	0.541	0.019 (Multiple), -0.030 (Adjusted)	-0.529, 0.301
65-80 Healthy Weight & Obese (Combined)	0.315	0.307	6.777	**0.032**	0.094 (Multiple), 0.075 (Adjusted)	0.028, 0.541

Table 13 illustrates the results from these various statistical analyses for both the healthy weight and obese groups between inaccuracy and body mass index. The r-squared value for healthy weight individual is greater (0.025) than that of the obese weight group (0.005), indicating that individuals with healthy body mass index levels account for more of the variation. In addition, the slope of the healthy weight group (0.899) is greater than that of the obese individuals (0.151), indicating that a more positive inaccuracy increases at a greater rate as body mass also rises in those exhibiting healthy weight (Fig. 13). Both body mass index groups

possess a non-significant difference for the p-value as also illustrated in Table 13. The healthy weight group possess a correlation coefficient (r-value) of 0.158, while the obese cohort exhibits an r-value of 0.075.

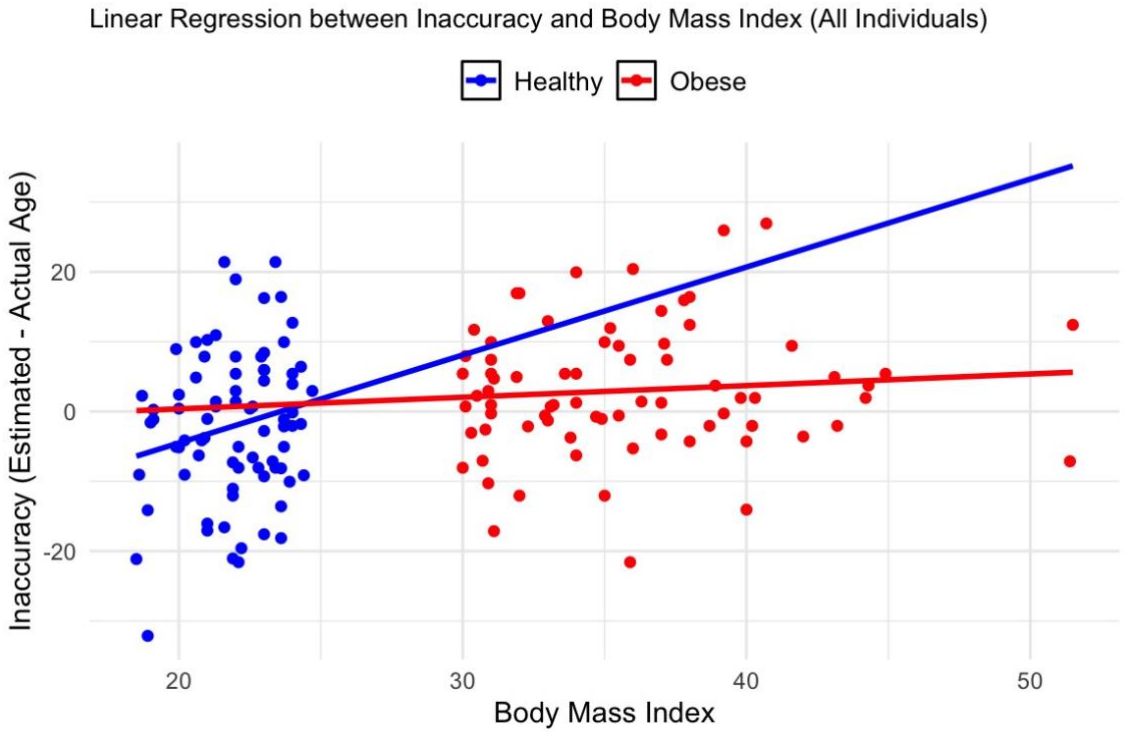

Figure 13: Scatterplot of linear regression between all healthy weight and obese individuals illustrating the directionality of the body mass levels.

Identical statistical analyses were also conducted for all individuals from both body mass index groups simultaneously. Thus, all 151 individuals from this study were analyzed together. As seen in Figure 14 and Table 13, a slope of 0.375 and a correlation coefficient (r-value) of 0.307 is present when both body mass index groups are examined simultaneously. A significant difference of 0.001 is present, and the r-squared value accounts for 9.4% of the variation. A positive slope indicates that as body mass index increases, so does inaccuracy. A positive correlation coefficient (r-value) of 0.307 implies a moderate positive relationship, which can also

be used to suggest that inaccuracy and body mass index are positively correlated and increase directly.

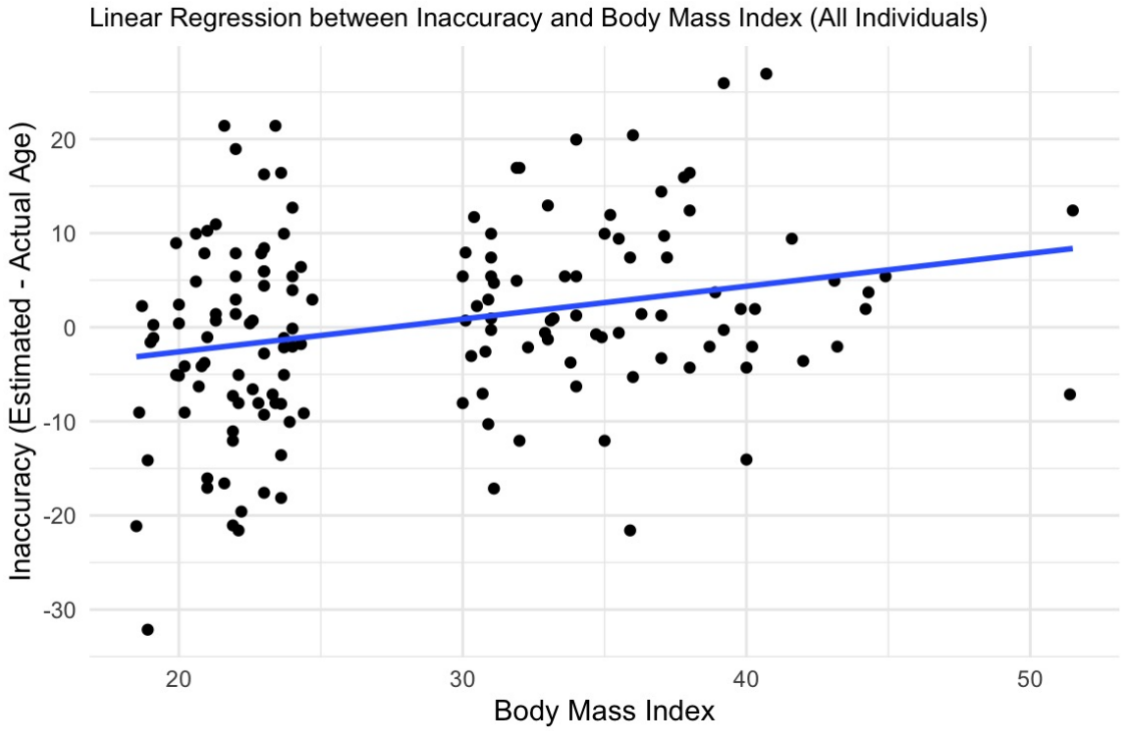

Figure 14: Scatterplot of linear regression between all healthy weight and obese individuals illustrating the directionality of the body mass levels when examined simultaneously.

Linear regression and Pearson's correlation test were also applied to males and females, with Table 14 highlighting the results between healthy weight and obese weight individuals from both biological sexes. Healthy females exhibit a greater slope (1.446), correlation coefficient (r-value) (0.245), and r-squared value (0.060) than obese females, however both sets of biological females possess positive figures in each of these statistics. This indicates that healthy females experience a stronger relationship between inaccuracy and body mass index, but obese females still also exhibit a positive trend between the two variables. The graph for these findings is found in Figure 15. When the body mass levels are examined simultaneously for biological females, there is a positive slope value of 0.377, correlation coefficient (r-value) of 0.304, and r-squared

of 0.092 (9.2% of the variation). It is also revealed that a significant difference is present when these two groups are not examined independently (p = 0.007). The holistic analysis for both body mass levels for biological females is found in Figure 16.

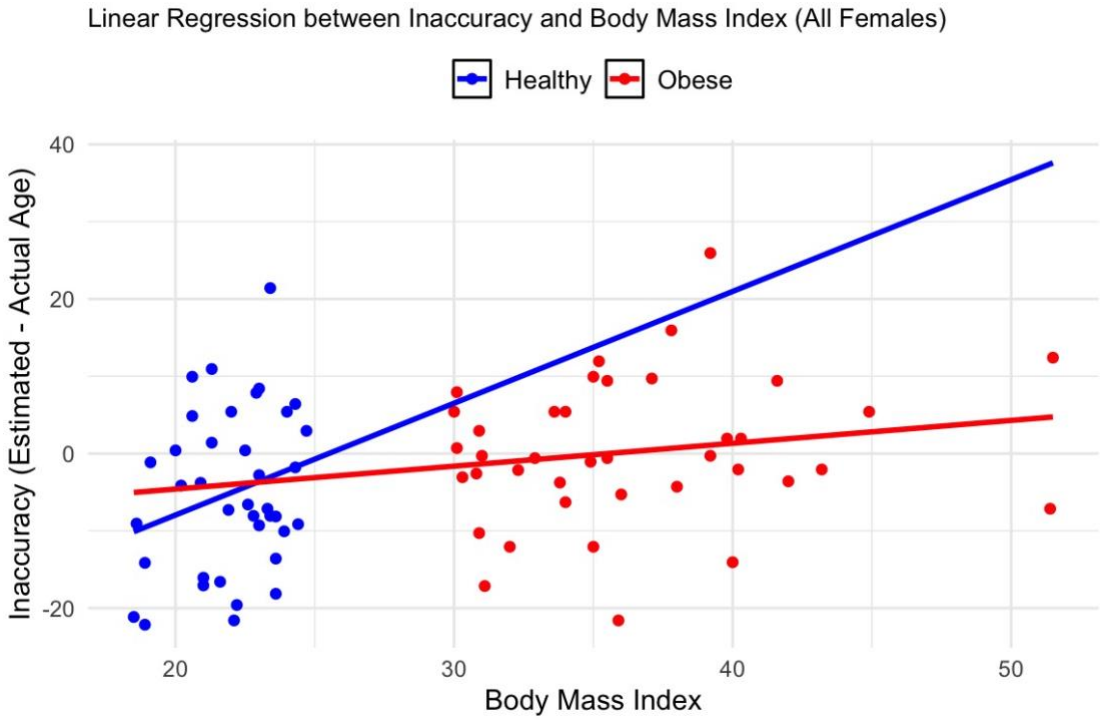

Figure 15: Scatterplot of linear regression between all biological females illustrating the directionality of the body mass levels.

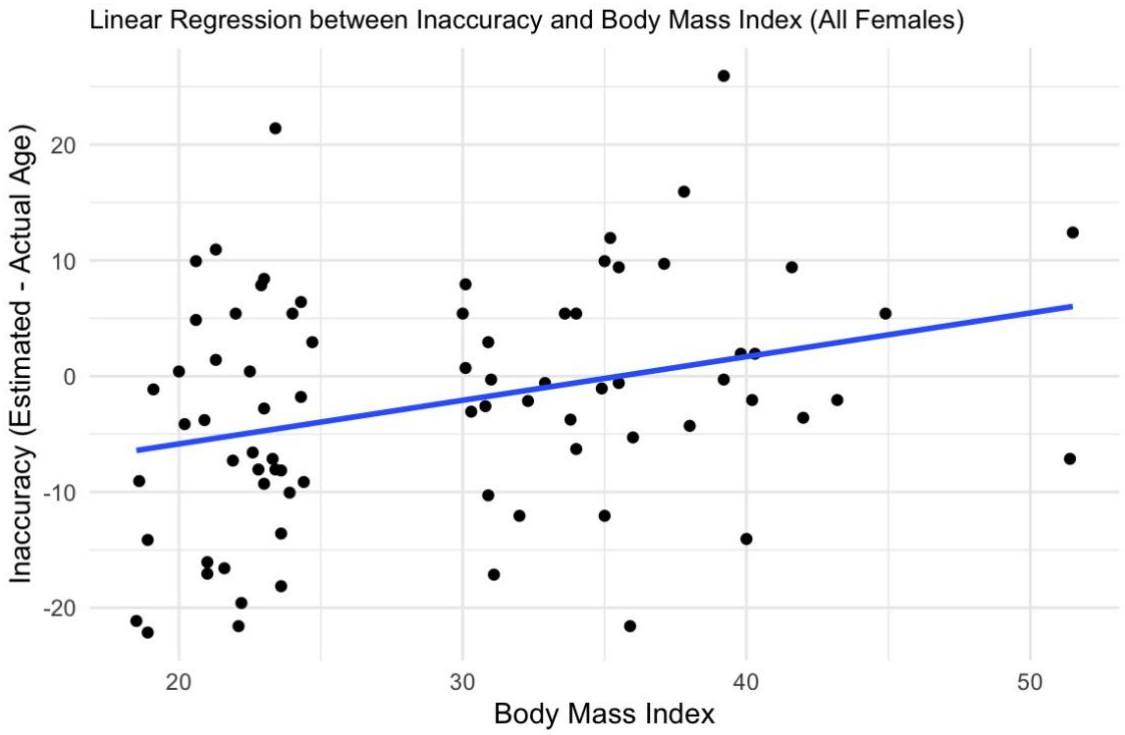

Figure 16: Scatterplot of linear regression between all biological females illustrating the directionality of the body mass levels when examined simultaneously.

The results from the test of linear regression and Pearson's correlation for biological males can also be found in Table 14. Healthy weight males are found to exhibit a greater slope (0.899), correlation coefficient (r-value) (0.158), and r-squared value (0.025) than the healthy weight counterparts. Thus, it can be stated that a more direct relationship exists between inaccuracy and body mass for the healthy weight cohort. These findings are illustrated in Figure 17. Both body mass levels analyzed simultaneously reveal a positive slope of 0.375, r-value of 0.307, and r-squared value of 0.094 which accounts for 9.4% of the variation. Table 14 also illustrates the close similarities in the statistics between males and females when both body mass levels are tested together. Figure 14 represents the statistical findings for biological males when obese and healthy weights are examined simultaneously.

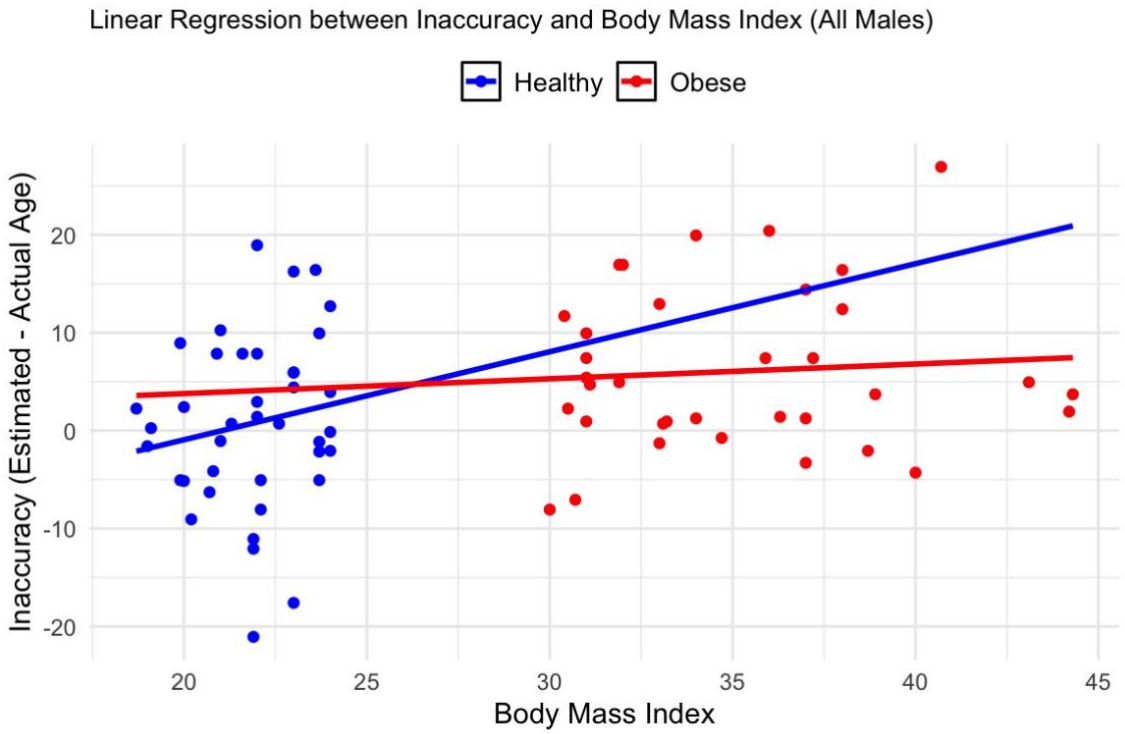

Figure 17: Scatterplot of linear regression between all biological males illustrating the directionality of the body mass levels.

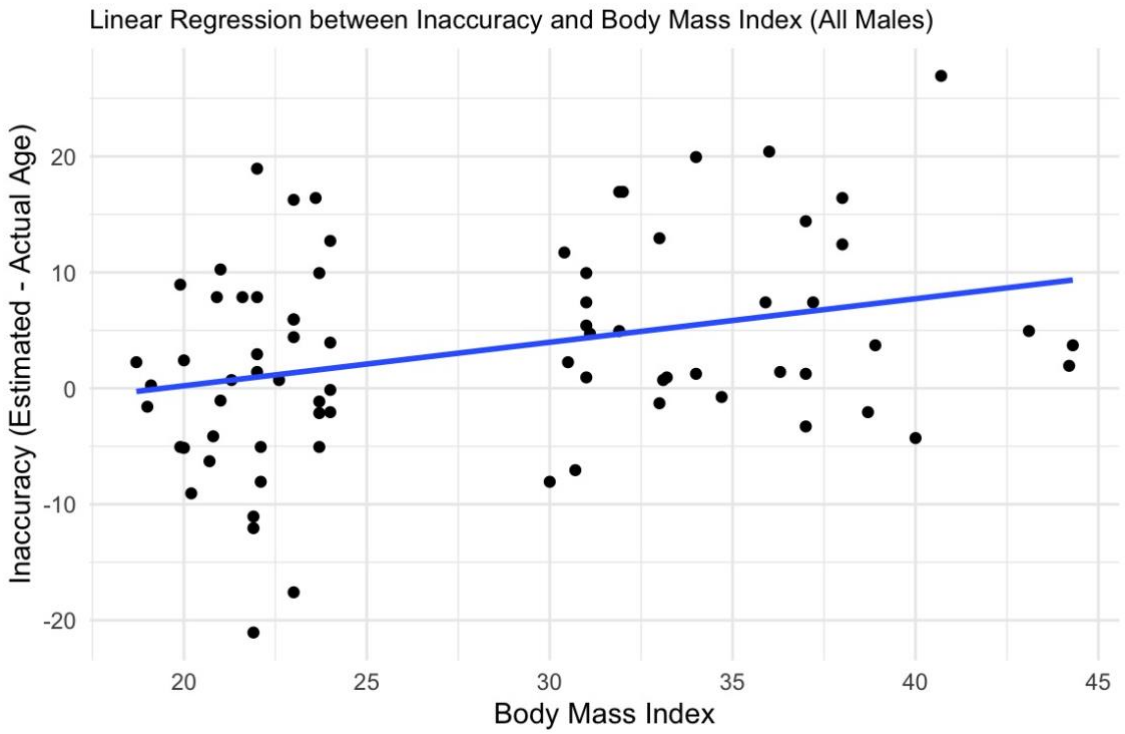

Figure 18: Scatterplot of linear regression between all biological males illustrating the directionality of the body mass levels when examined simultaneously.

The various statistical analyses were also applied to the three age groups examined in this study. Similar to the biological sexes, each age cohort was first separated by healthy weight and obese weight to determine how the results from the linear regression and Pearson's correlation test differed between body mass levels. These results can be found in Table 15 and in Figures 19-21. In the "young" age group, or individuals between 30-49 years of age, the healthy weight cohort exhibits a greater slope (0.157) and correlation coefficient (r-value) (0.028) than the obese counterparts. This indicates a more positive relationship between inaccuracy and body mass index is witnessed in healthy weight individuals rather than those who exhibit obese BMI levels (Fig. 19). However, both healthy and obese groups possess an identical r-squared value of 0.008, which accounts for 0.80% of the variation. Healthy weight individuals also exhibit more positive statistics, such as slope (1.573) and correlation coefficient (r-value) (0.317), than the obese

counterparts in the 50-64 age group, as indicated in Table 15. Similarly to the 30-49 age cohort, it can be understood that healthy weight individuals possess a stronger relationship between inaccuracy and body mass compared to those who exhibit obese body mass levels (Fig. 20). The healthy weight individuals also possess a greater r-squared value (10.1%) than those exhibiting an obese body mass index level (0.40%), indicating that more variation is accounted for among those with a healthy BMI. Both healthy and obese individuals from the 65-80 age group possess negative slopes and correlation coefficients (r-values), indicating that as body mass increases, inaccuracy decreases (Fig. 21). Similar to the 50-64 age cohort, the healthy weight individuals from the 65-80 age group account for more variation than the obese counterparts based on the r-squared value. Healthy weight individuals exhibit a 0.033 value, while the obese counterparts possess only a 0.019 figure in this statistic.

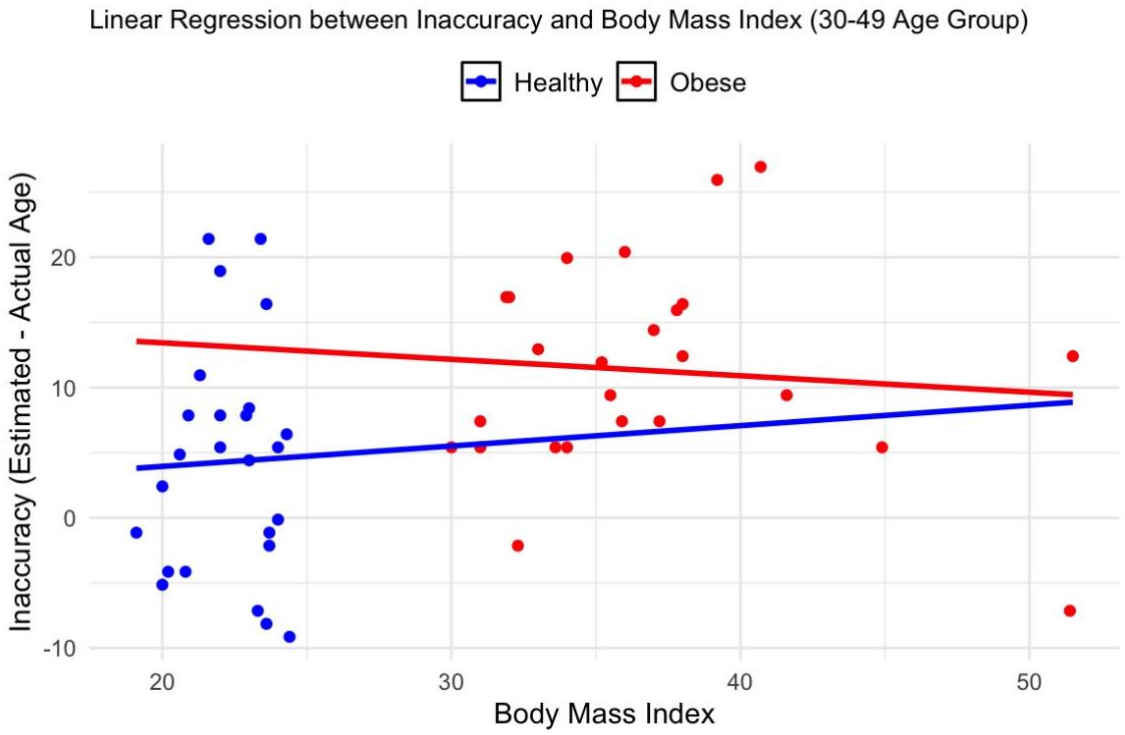

Figure 19: Scatterplot of linear regression between all individuals between 30-49 years-of-age at time of death illustrating the directionality of each body mass level.

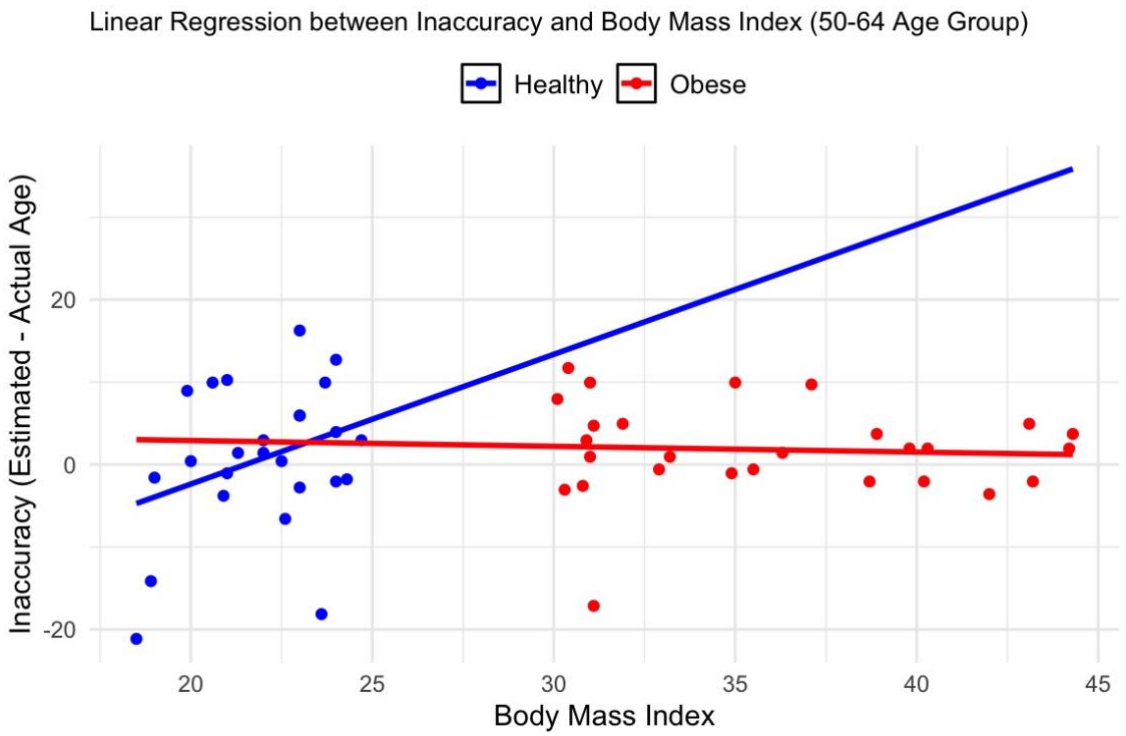

Figure 20: Scatterplot of linear regression between all individuals between 50-64 years-of-age at time of death illustrating the directionality of each body mass level.

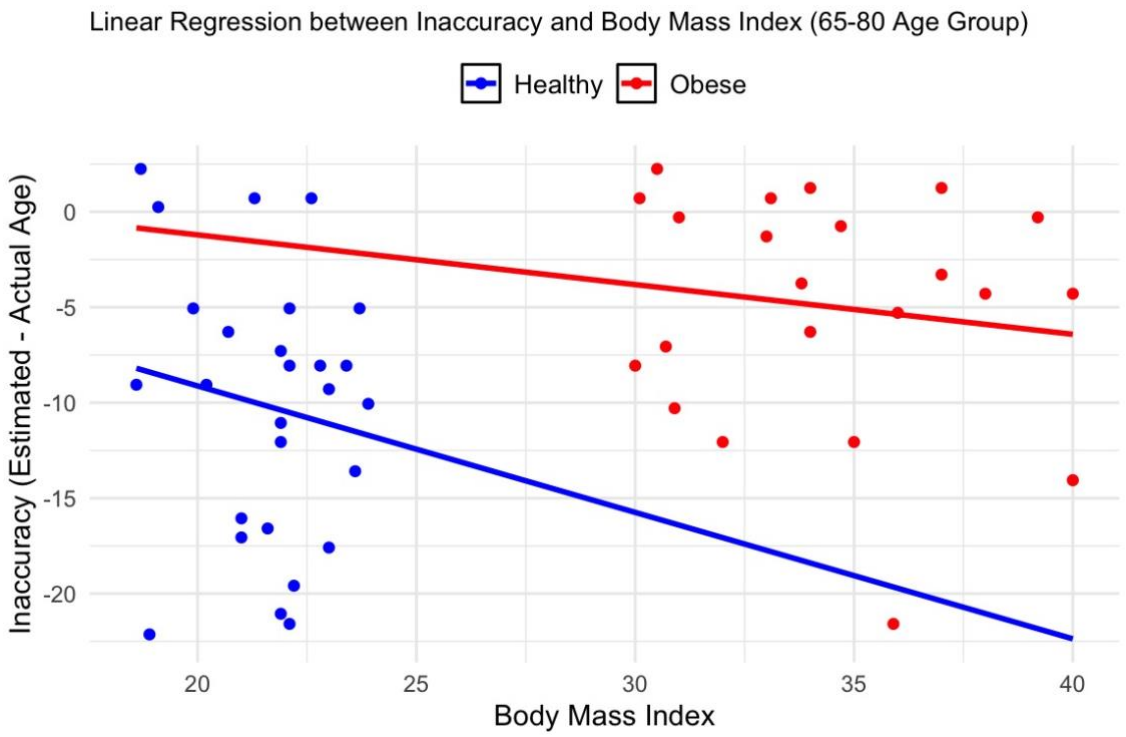

Figure 21: Scatterplot of linear regression between all individuals between 65-80 years-of-age at time of death illustrating the directionality of each body mass level.

In addition to examining both body mass levels independently between the three age groups, both healthy weight and obese weight individuals were analyzed simultaneously, as also seen in Table 15 and in Figures 22-24. Both age cohorts of 30-49 and 65-80 exhibit a slope of above 0.300, while the 50-64 age group possess a value of only 0.081. The 50-64 age cohort also possesses the smallest correlation coefficient (r-value) of only 0.086, while also accounting for the least amount of variation with an r-squared value of 0.007 (0.70%). These results indicate that the least positive increase between inaccuracy and body mass level was witnessed in the 50-64 age group when healthy weight and obese individuals were examined simultaneously.

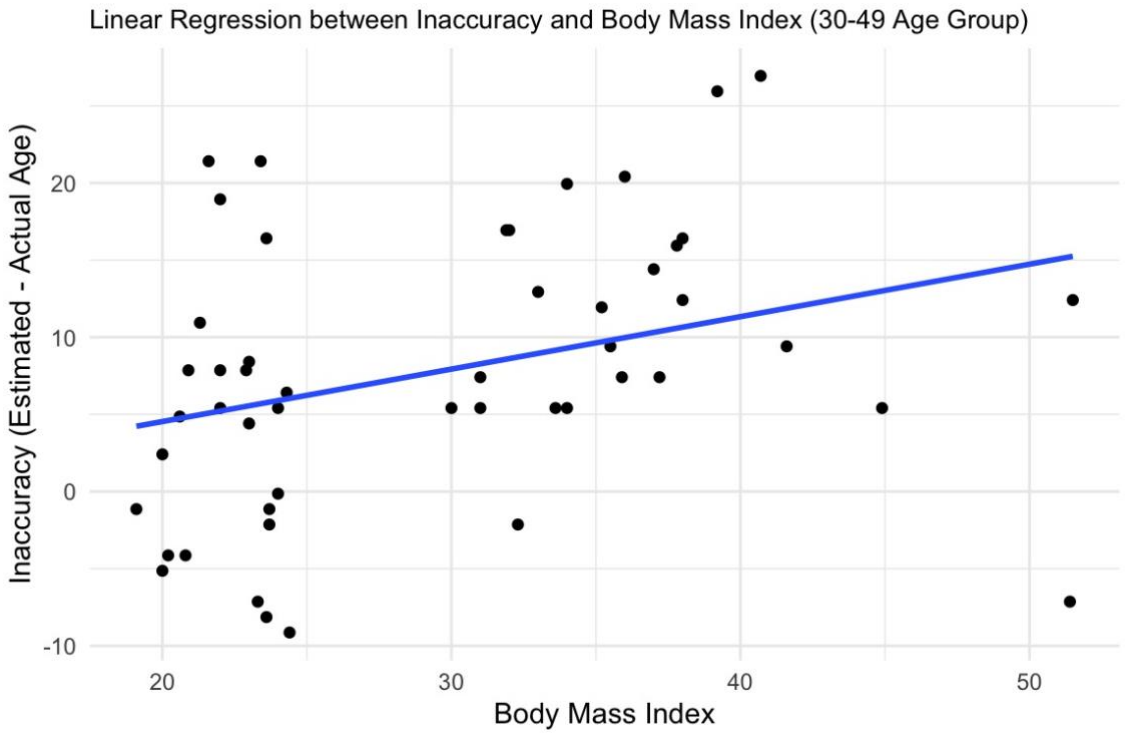

Figure 22: Scatterplot of linear regression between all individuals between 30-49 years-of-age at time of death illustrating the directionality of the body mass levels when examined simultaneously.

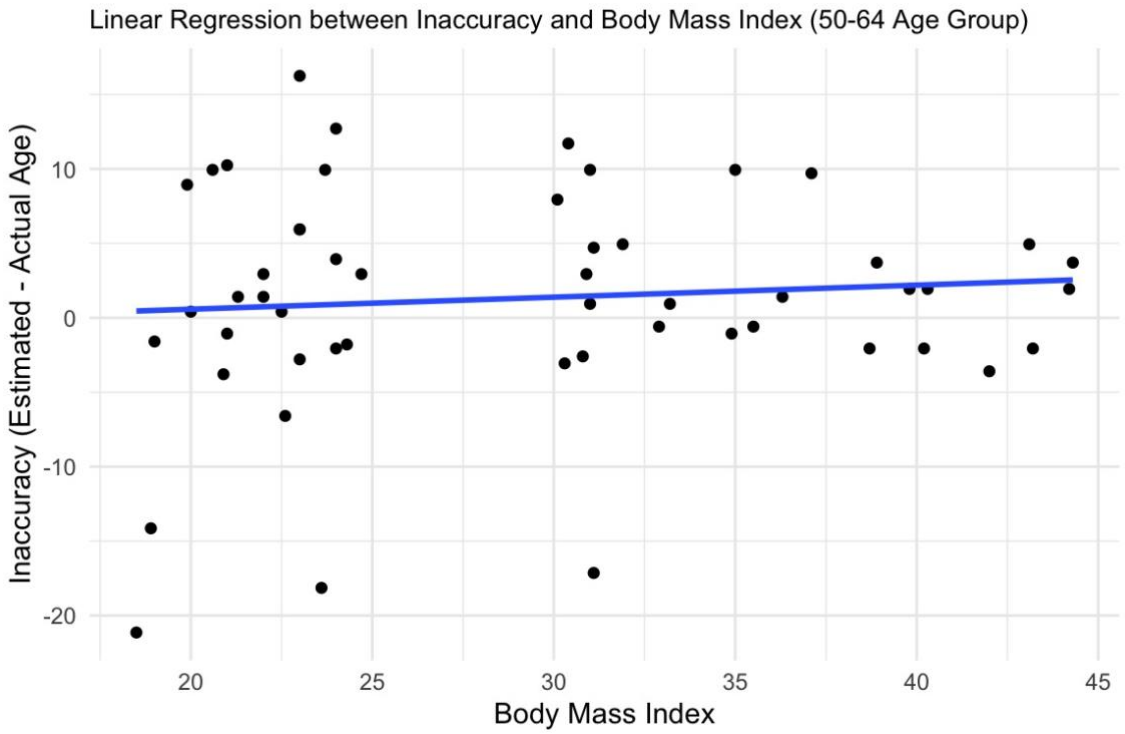

Figure 23: Scatterplot of linear regression between all individuals between 50-64 years-of-age at time of death illustrating the directionality of the body mass levels when examined simultaneously.

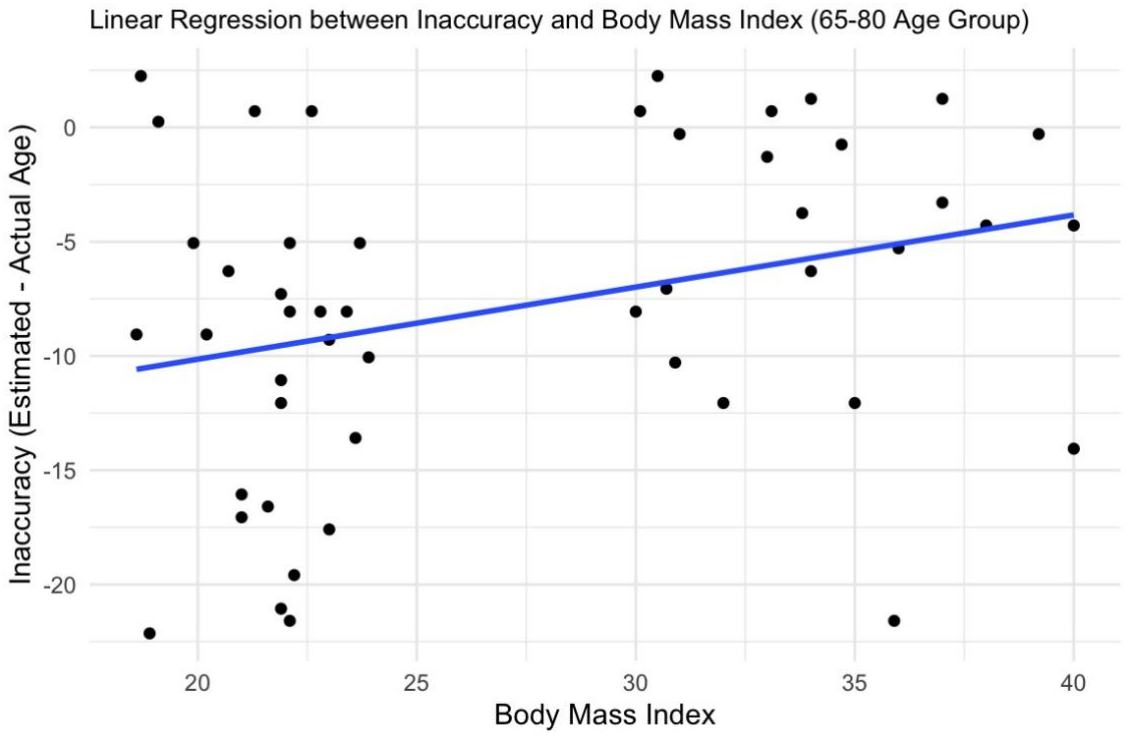

Figure 24: Scatterplot of linear regression between all individuals between 65-80 years-of-age at time of death illustrating the directionality the two body mass levels when examined simultaneously.

5.3 T-tests

T-tests were conducted between inaccuracy rates for both healthy and obese weight individuals for each of the three age groups examined in this study, as well as both biological sexes to determine the mean value, the 95 percent confidence interval, and p-value. The results for the t-tests for the three age groups can be found in Table 16. The 30-49 age group exhibits a significant difference between the mean values of the healthy and obese groups ($p = 0.005$), with obese individuals possessing a greater mean and overall higher values of inaccuracy. These findings are illustrated in Figure 25. Similar to the 30-49 age cohort, obese individuals also exhibit a greater mean value and overall higher rates of inaccuracy than the healthy counterparts in the 50-64 age group (Fig. 26). However, these two groups do not present a significant

difference (p = 0.644). Figure 27 illustrates the t-test of individuals between the ages of 65-80. Both healthy weight and obese groups exhibit negative rates of inaccuracy; however, obese individuals, once again, possess a greater, or more positive, value. Similar to the 30-49 age group, there is a significant difference between the two body mass levels in the 65-80 age category (p = 0.009).

Table 16: T-test results for inaccuracy rates for all age groups

Age Group	Mean	95 percent confidence interval	p-value
30-49	4.304 (healthy), 11.296 (obese)	-11.754, -2.229	0.005
50-64	0.811 (healthy), 1.796 (obese)	-5.264, 3.294	0.664
65-80	-10.551 (healthy), -5.038 (obese)	-9.778, -0.748	0.023

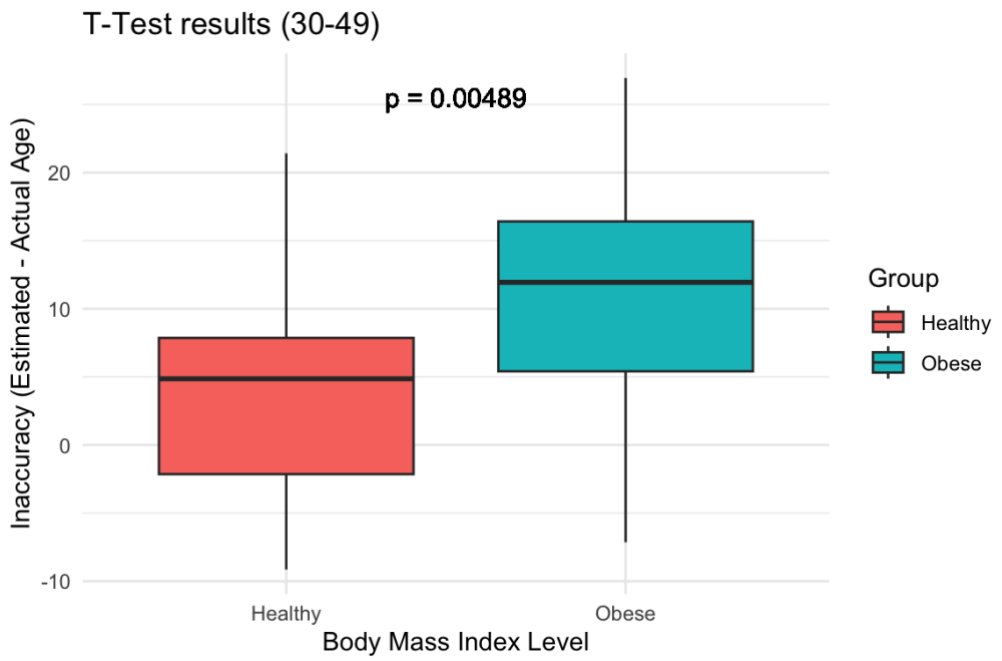

Figure 25: T-test results for inaccuracy rates between individuals between 30-49 years-of-age at death from both healthy and obese body mass levels.

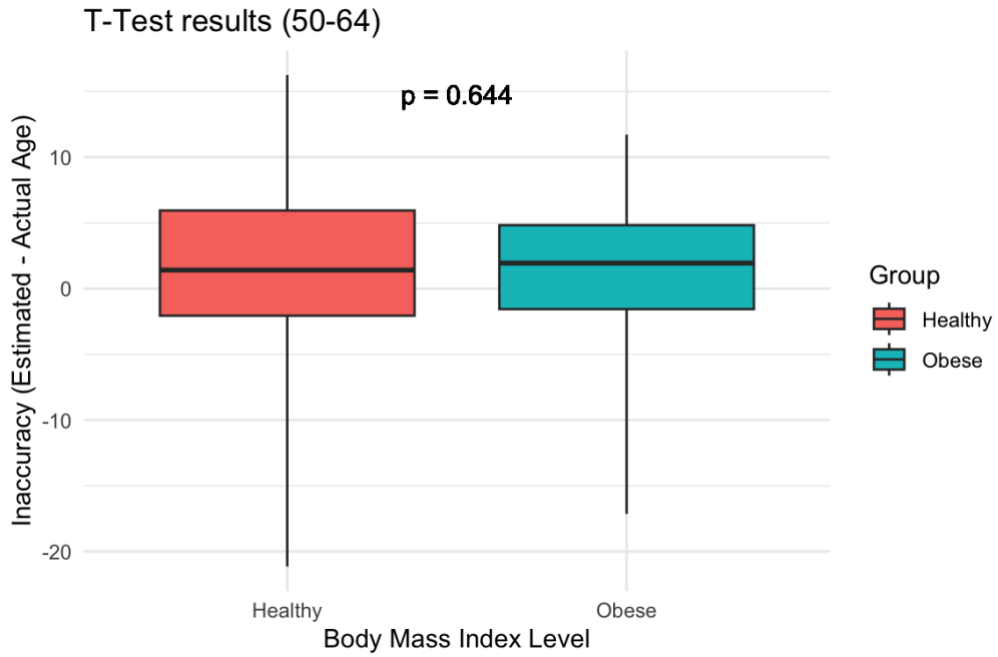

Figure 26: T-test results for inaccuracy rates between individuals between 50-64 years-of-age at death from both healthy and obese body mass levels.

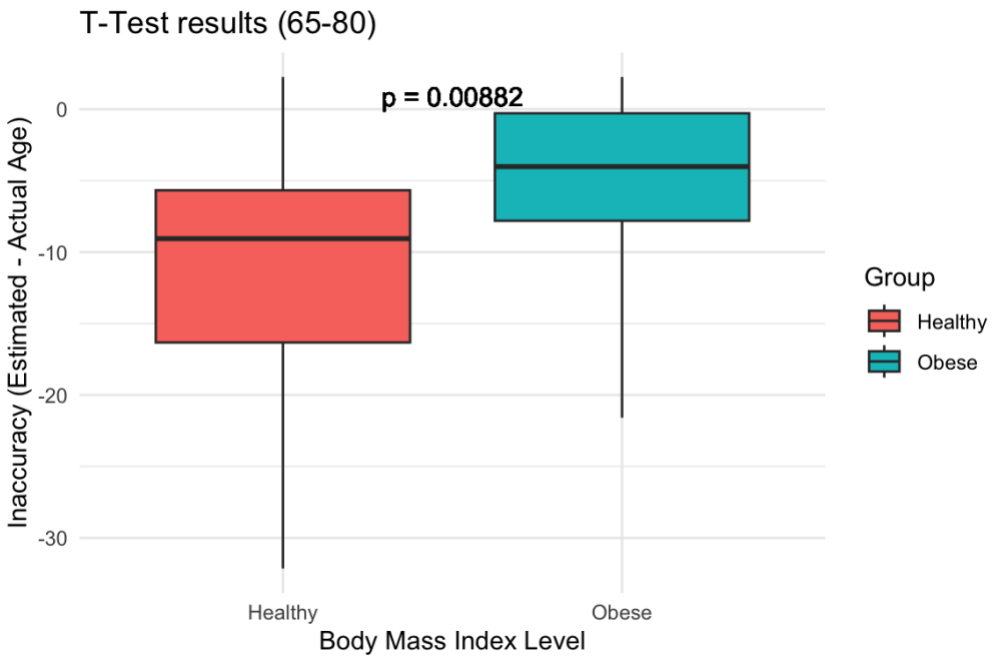

Figure 27: T-test results for inaccuracy rates between individuals between 65-80 years-of-age at death from both healthy and obese body mass levels.

Additional t-tests were also run between inaccuracy rates for both body mass levels for biological males and females, with the results listed in Table 17. Males exhibit greater mean values for both the healthy (0.773) and obese cohorts (6.072) compared to healthy (-5.012) and obese (0.244) females.

Table 17: T-test results for inaccuracy rates for both biological sexes.

Biological Sex	Mean	95 percent confidence interval	p-value
Males	0.773 (Healthy), 6.072 (Obese)	-9.261, -1.337	0.009
Females	-5.012 (Healthy), 0.244 (Obese)	-9.778, -0.748	0.023

Figure 28 illustrates the results from the t-test for males, which further indicates that the obese individuals exhibit a greater mean value than the healthy weight counterparts. In addition, a significant difference exists between both body mass level in biological males ($p = 0.009$). Similar to males, obese biological females also express a greater mean value for inaccuracy than the healthy weight group (Table 17; Fig. 29). These findings also indicate obese females are overestimated in age-at-death compared to the healthy weight counterparts. There is also a significant difference between the two body mass levels for biological females ($p = 0.023$); however, this value is lower than that of the males. The values from the 95 percent confidence interval are the upper and lower bounds, which can be used provide a range at where the true difference in mean values is between the groups.

Figure 28: T-test results for inaccuracy between individuals between biological males from both healthy and obese body mass levels.

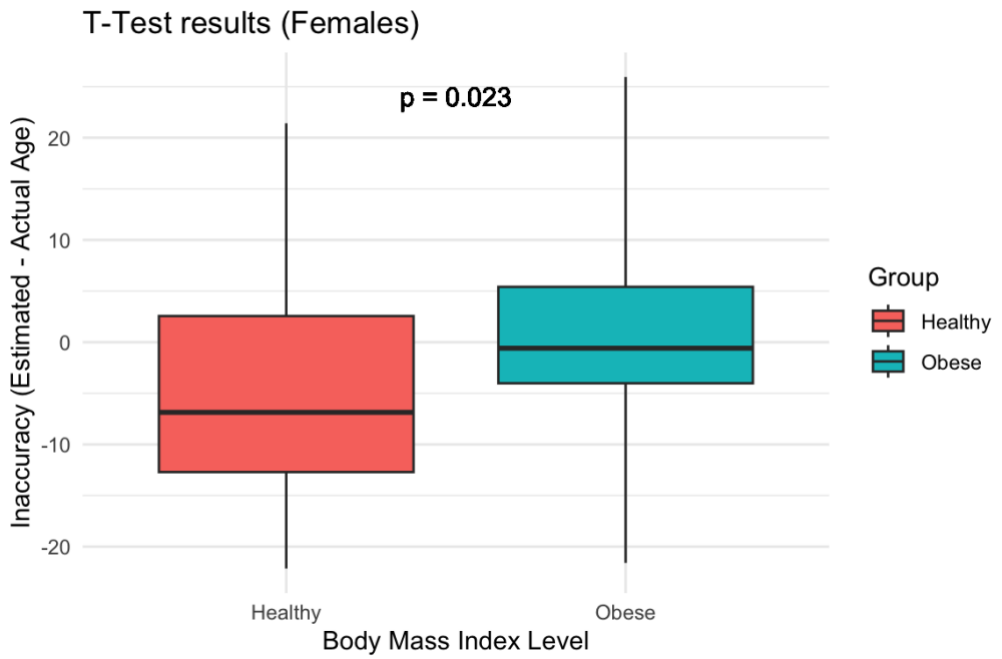

Figure 29: T-test results for inaccuracy rates between biological females from both healthy and obese body mass levels.

5.4 ANOVA (Analysis of Variance)

ANOVA, or analysis of variance, was also used to compare mean values between three or more groups to determine if any statistically significant differences were present. ANOVA was only administered to rates of inaccuracy in comparison to body mass levels as it is a parametric, or continuous, variable. This statistical analysis was performed on both the age groups and biological sexes examined in this study, and these results for each can be found in Tables 18 and 19.

Table 18: ANOVA results for inaccuracy rates between age groups and body mass levels

ANOVA	Sum sq	Mean sq	F-value	Pr(>F)
Group	7053	1410.7	24.86	<2e-16

Residuals	8228	56.7	N/A	N/A

Table 19: ANOVA results for inaccuracy rates between biological sex and body mass levels

ANOVA	Sum sq	Mean sq	F-value	Pr(>F)
Group	2248	794.4	8.691	2.4e-05
Residuals	12676	86.2	N/A	N/A

The first ANOVA was conducted to compare the mean value of inaccuracy rates for the three age cohorts with “young” signifying the 30-49 cohort, “middle” indicating the 50-64 age group, and “old” describing individuals between 65-80 years-of-age at death (Fig. 30). Each of the three age groups all witness the obese individuals exhibit greater mean values compared to the healthy weight counterparts (Fig. 30).

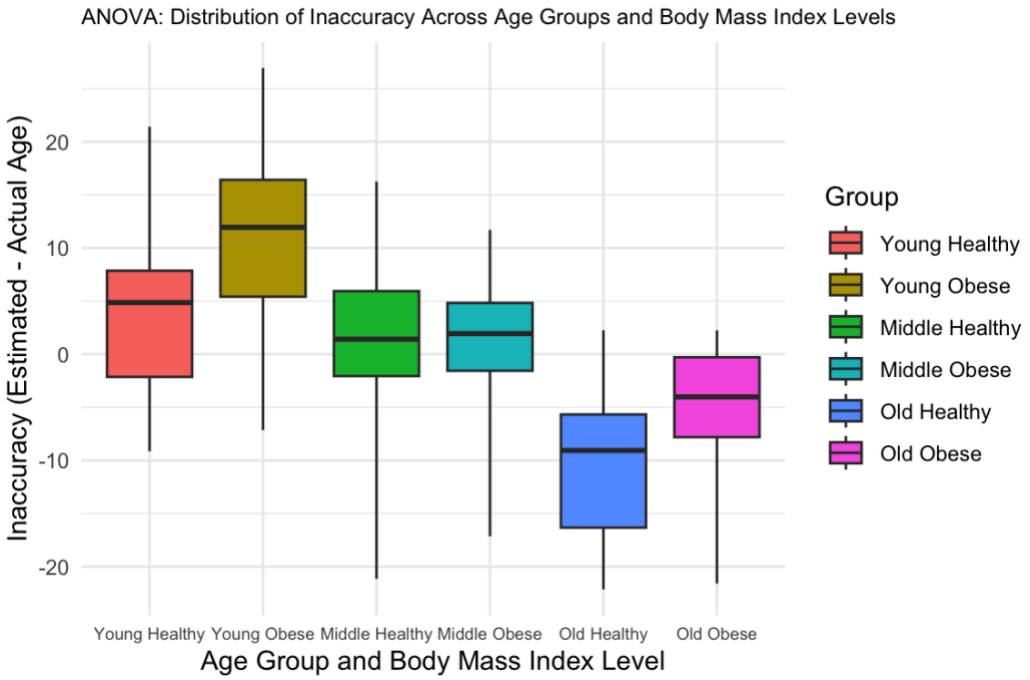

Figure 30: ANOVA results illustrating the values of inaccuracy rates for each of the three age groups along with body mass level.

These findings signify that obese individuals were, on average, overestimated for age-at-death compared to healthy weight counterparts. However, the ANOVA reveals a significant difference exists between these groups (p = 2.4e-05). Thus, a Tukey's Honestly Significant Difference (HSD) test was applied to determine which group from each ANOVA were significantly different. The results from the Tukey's HSD for the ANOVA between the three age cohorts can be found in Table 20.

Table 20: Tukey's HSD results for inaccuracy rates between age groups and body mass levels. Only groups with a significantly different p-value (<0.05) are listed.

Groups in comparison (Inaccuracy)	diff	lwr	upr	p adj
Old Obese-Middle Healthy	2.280	1.024	3.536	0.000008

Young Healthy-Middle Healthy	-2.040	-3.255	-0.825	0.00005
Old Obese-Middle Obese	1.926	0.692	3.160	0.0002
Young Healthy-Middle Obese	-2.394	-3.587	-1.202	0.0000006
Old Obese-Old Healthy	1.593	0.359	2.826	0.004
Young Healthy-Old Healthy	-2.727	-3.920	-1.535	0.0000000
Young Obese-Old Healthy	-1.327	-2.520	-0.135	0.020
Young Healthy-Old Obese	-4.320	-5.576	-3.064	0.0000000
Young Obese-Old Obese	-2.920	-4.176	-1.664	0.0000000
Young Obese-Young Healthy	1.400	0.185	2.615	0.014

A majority of comparisons exhibit a significant difference, but three, in particular, are distinct from the rest. These include “young” healthy-“old” healthy, “young” healthy-“old” obese, and “young” obese-old healthy, all of which exhibit a p-value of 0.0000000 (Table 16). Figure 30 also reveals that the obese cohorts exhibit greater mean values in each of the three age group compared to their healthy weight counterparts. This further implies that obese individuals are overestimated in terms of age compared to those exhibiting healthy weight body mass levels. Additionally, as age increases, rates of inaccuracy decrease (Fig. 30). Similar findings have been discovered in previous studies, particularly when the Buckberry and Chamberlain (2002) method was employed.

An ANOVA was also conducted between inaccuracy and body mass level between biological males and females. Similarly to the test on the three age groups, a significant difference is present between the biological sexes, ($p = <2e\text{-}16$), and the overall results from the

ANOVA can be found in Table 21. Figure 31 illustrates the results from this test with both healthy and obese males and females listed.

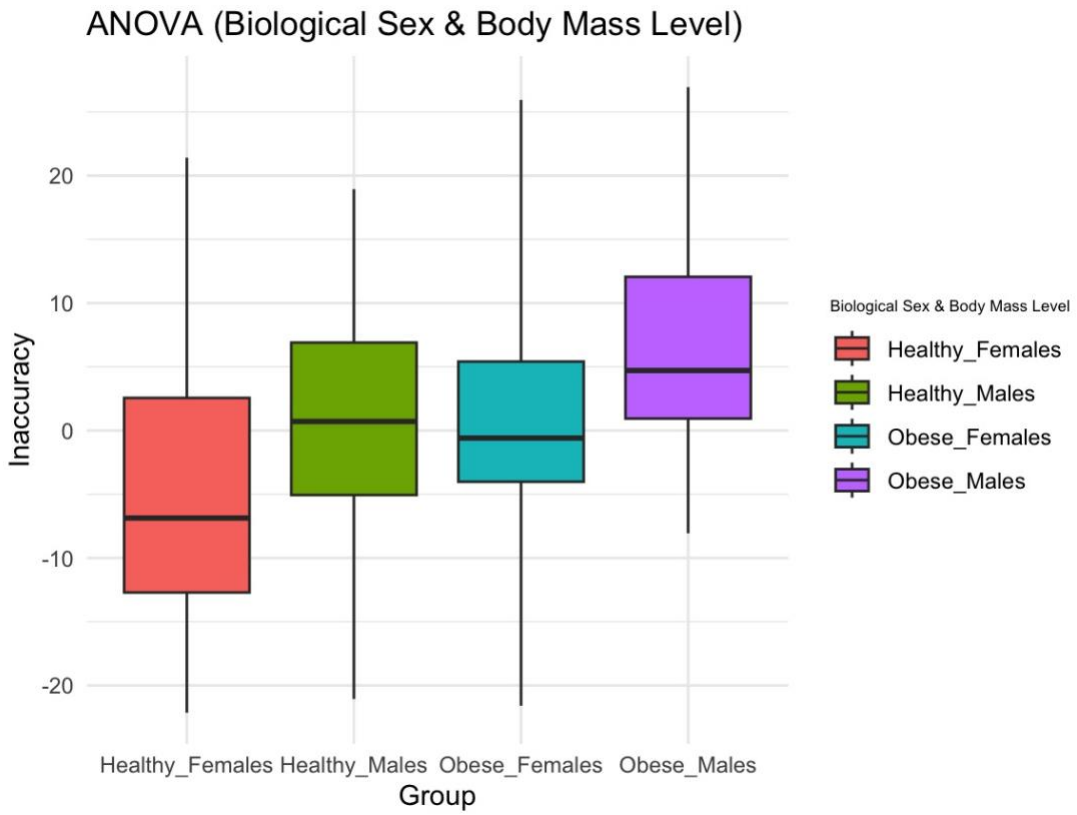

Figure 31:ANOVA results illustrating the values of inaccuracy rates for both biological males and females along with body mass level.

A Tukey's HSD was also applied in this scenario, and the groups that exhibit a significant difference are highlighted in Table 21. Obese males-healthy females exhibit the greatest significant difference for all comparisons between the sexes ($p = 0.0000006$). This is also reflected in the illustration of the ANOVA (Fig. 31), with these two groups possessing the widest disparity in terms of overall values. Figure 31 and Table 21 are also useful because they reveal that males are typically overestimated in terms of age compared to females, which indicates that sexual dimorphism may be present in age-related changes of auricular surface morphology.

Table 21: Tukey's HSD results for inaccuracy rates between biological sex and body mass level. Only groups with a significantly different p-value (<0.05) are listed.

Groups in comparison (Inaccuracy)	diff	lwr	Upr	p adj
Healthy Males-Healthy Females	5.792	0.291	11.292	0.035
Obese Males-Healthy Females	11.091	5.437	16.744	0.000006
Obese Males-Obese Females	5.828	0.209	11.446	0.039

In order to further understand the influence of obesity in age-at-death estimating from auricular surface morphology, the total composite scores assigned to each individual based on the Buckberry and Chamberlain (2002) scoring criteria were analyzed alongside body mass level. As these scores are non-parametric, or noncontinuous, data, a Kruskal-Wallis test was implemented rather than ANOVA to compare the mean values between the samples examined to determine if significant differences exist.

Similar to the ANOVA, A Kruskal-Wallis test was employed between the three age groups as well as biological sexes for both healthy and obese individuals. Table 22 highlights the results from this test for the 30-49, 50-64, and 65-80 age cohorts, and a p-value of 8.091e-13 indicates that a significant difference exists between these groups.

Table 22: Kruskal-Wallis results for total composite scores between age groups and body mass levels.

Kruskal-Wallis	Chi-squared	Degrees of Freedom	p-value
Values	65.682	5	8.091e-13

Table 23: Kruskal-Wallis results for total composite scores between biological sex and body mass levels

Composite Score (Biological Sex and Body Mass)	Chi-squared	Degrees of Freedom	p-value
Values	24.017	3	2.477e-05

Similarly, the p-value of 2.477e-05 between biological males and females also signifies a significant difference exists between the two sexes (Table 23). The Kruskal-Wallis test between age groups is illustrated in Figure 32 and Figure 33 graphs the findings between biological males and females.

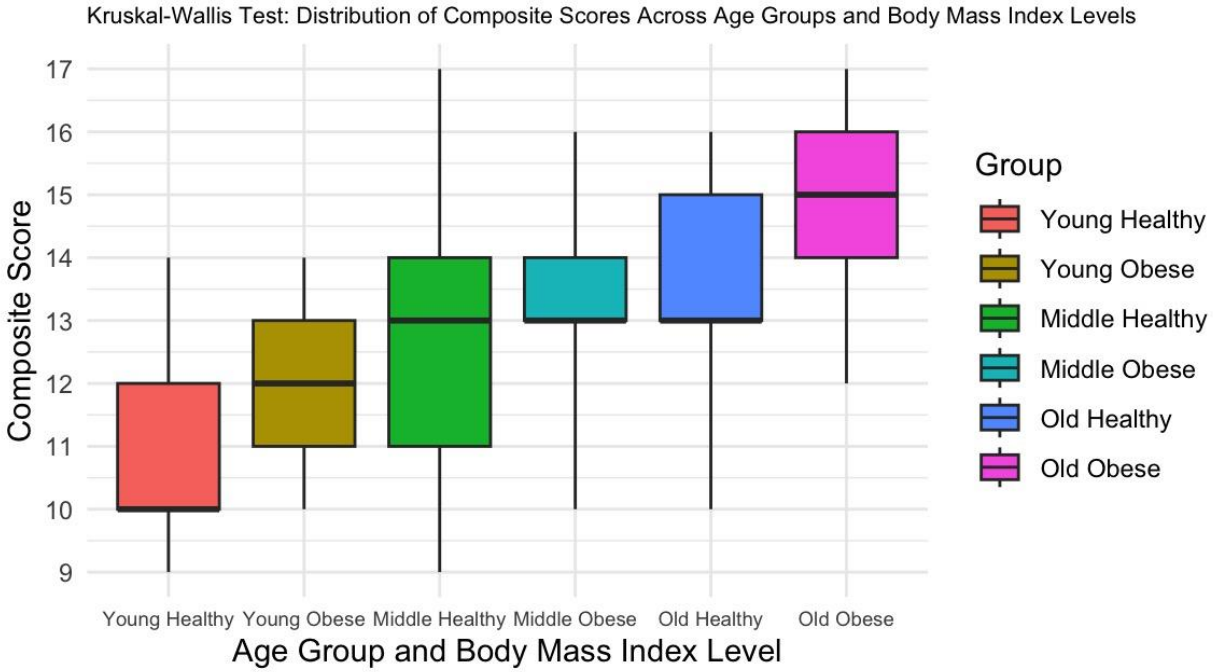

Figure 32: Kruskal-Wallis results illustrating the values of composite scores for both biological males and females along with body mass level.

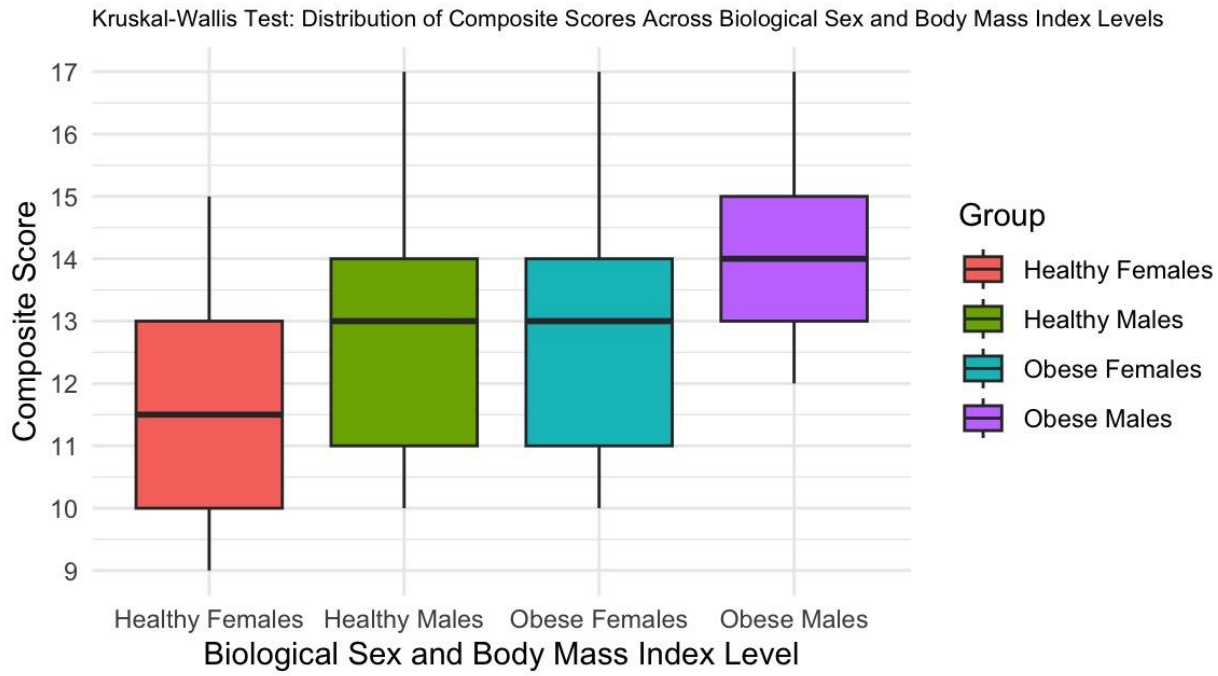

Figure 33: Kruskal-Wallis results illustrating the values of composite scores for both biological males and females along with body mass level.

In order to determine which of the groups express a significant difference between each other, several independent Mann-Whitney U tests were conducted between the age groups as well as between biological males and females. The results from these tests can be found in Tables 24 & 25.

Table 24: Independent Mann-Whitney U results for total composite scores between age groups and body mass levels. Only groups with a significantly different p-value (<0.05) are listed.

Independent Mann-Whitney U	W	p adj
Young Obese-Young Healthy	492	0.0004
Middle Healthy-Young Healthy	122.5	0.0002
Middle Obese-Young Healthy	603	8.16e-07
Old Healthy-Young Healthy	585.5	6.878e-07

Old Obese-Young Healthy	541	1.055e-08
Middle Obese-Young Obese	490.5	0.004
Old Healthy-Young Obese	489	0.002
Old Obese-Young Obese	520.5	1.137e-07
Old Obese-Middle Healthy	89	6.309e-05
Old Obese-Middle Obese	492	6.246e-05
Old Obese-Old Healthy	447	0.0007

Table 25: Independent Mann-Whitney U results for total composite scores between biological sex and body mass levels. Only groups with a significantly different p-value (<0.05) are listed.

Independent Mann-Whitney U	W	p adj
Healthy Males-Healthy Females	486	0.009
Obese Females-Healthy Females	999.5	0.008
Obese Males-Healthy Females	1097.5	1.406e-06
Obese Males-Healthy Males	871	0.039
Obese Males-Obese Females	922	0.009

As illustrated in Table 24, a majority of the comparisons between age cohorts exhibit a significant difference. The comparison with the most significant difference between groups is the "young" healthy-"old" obese with a p-value of 1.055e-08. These findings are unsurprising as these two groups exhibit the most disperse overall values from the three age groups. Examining the Kruskal-Wallis test holistically reveals that obese individuals exhibit greater mean values compared to healthy weight counterparts in two of the three age cohorts. In both the 30-49 and 65-80 age groups, it can be stated that obese individuals exhibit a greater composite score, on

average, and therefore overestimated in age at a greater rate than those classified as healthy weight. However, both the “middle” healthy and obese cohorts for the 50-64 age group exhibit identical means. Thus, it is more difficult to determine if obese individuals are overestimated in age-at-death between these ages.

When composite scores between biological sexes are compared with the body mass levels, healthy females and obese males exhibit the lowest p value ($p = 1.406e-06$). These results are also to be expected as the two groups exhibit the greatest difference in overall values from all samples examined between both biological sexes. Similar to tests on inaccuracy, obese males and females exhibit greater mean values than healthy males and healthy females, respectively (Fig. 33).

In order to determine which of the five traits from the Buckberry and Chamberlain (2002) criteria were most indicative of age-at-death, scatterplots from various ordinal logistic regressions were between both body mass levels were created and can be found in Figures 34-38.

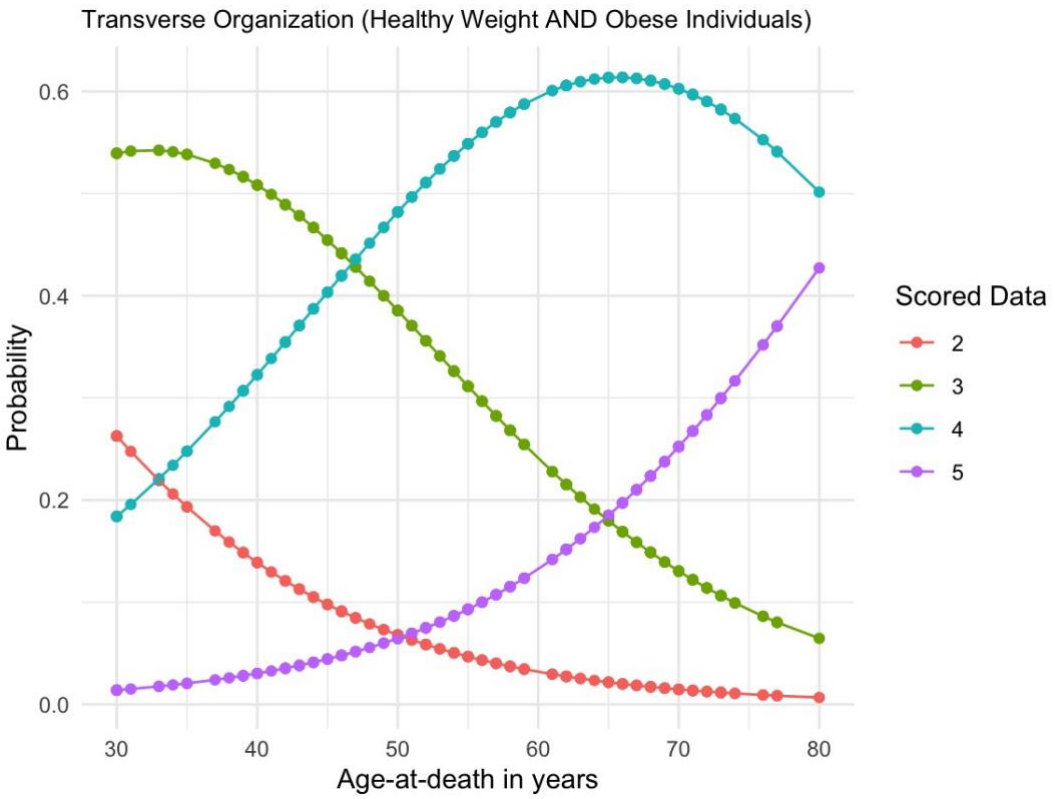

Figure 34: Scatterplot of an ordinal linear regression illustrating the probability of scaled scores assigned to an individual based on transverse organization of the auricular surface. No scores of "1" for transverse organization were found in the examination of the auricular surface in this study.

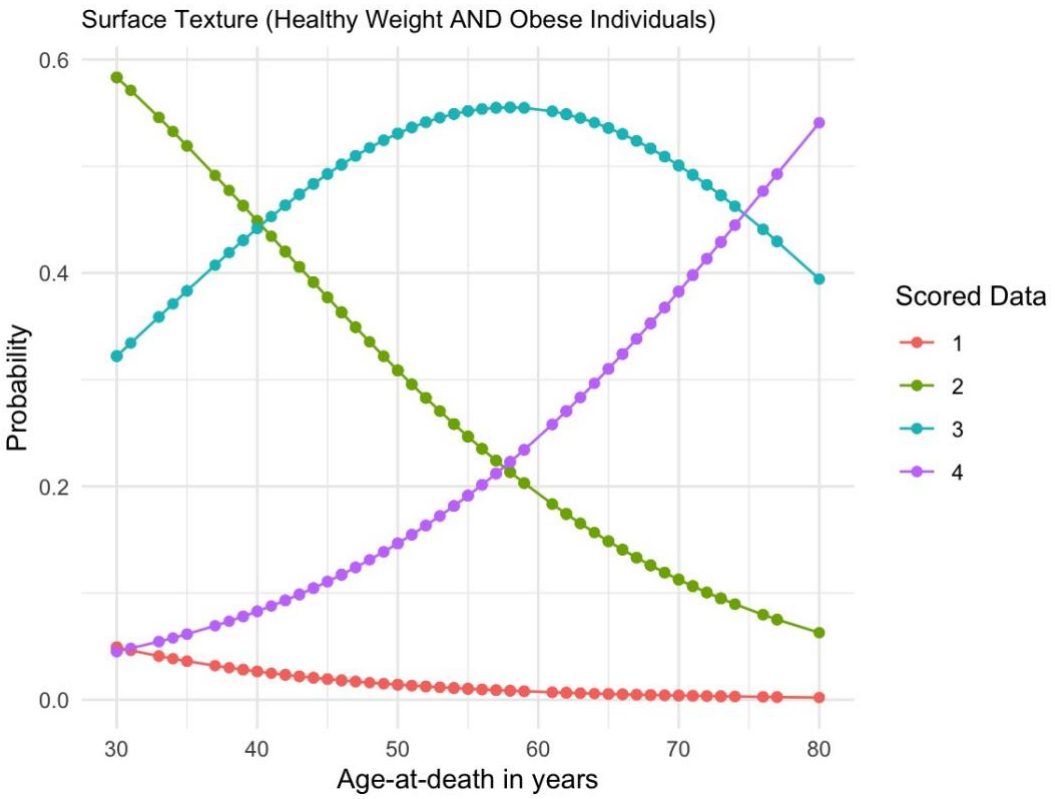

Figure 35: Scatterplot of an ordinal linear regression illustrating the probability of scaled scores assigned to an individual based on surface texture morphology of the auricular surface. No scores of "5" were found for surface textures in the examination of the auricular surface in this study.

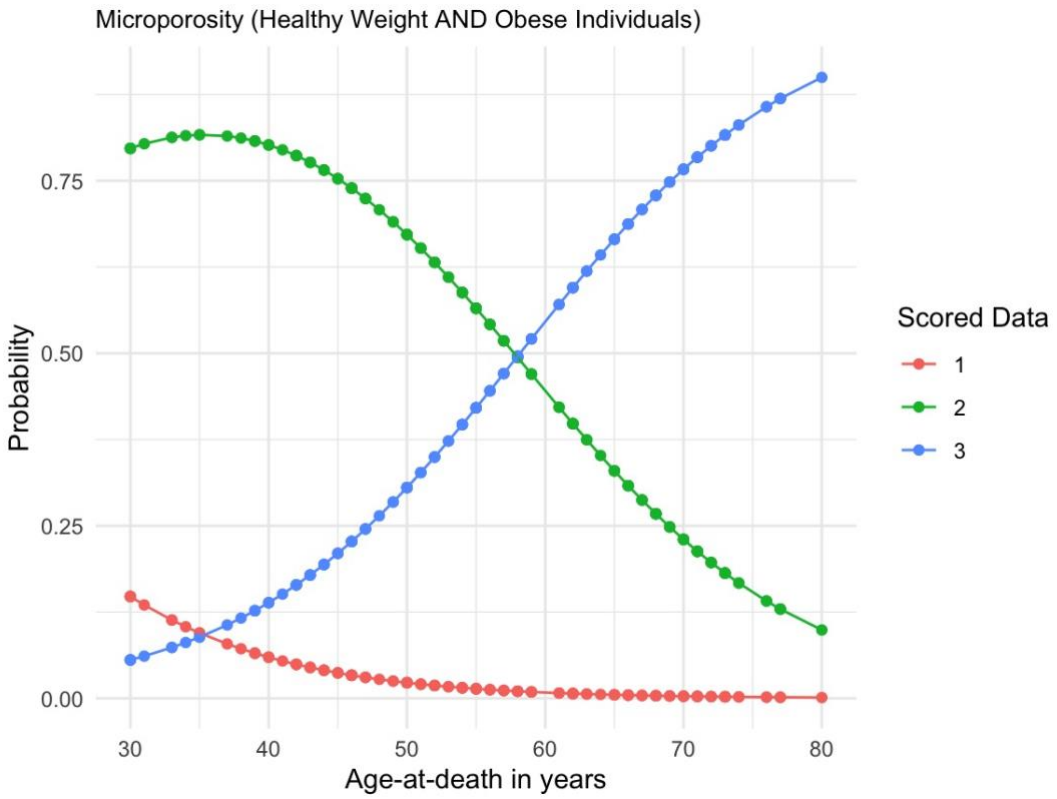

Figure 36: Scatterplot of an ordinal linear regression illustrating the probability of scaled scores assigned to an individual based on microporosity of the auricular surface.

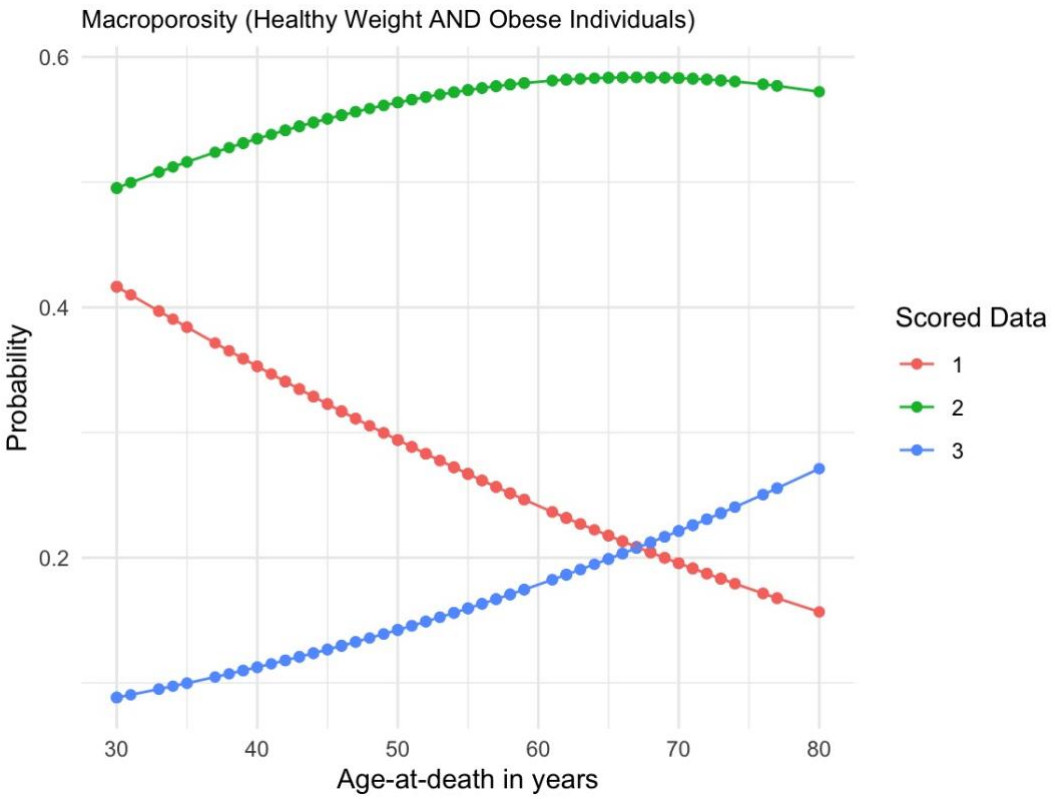

Figure 37: Scatterplot of an ordinal linear regression illustrating the probability of scaled scores assigned to an individual based on macroporosity of the auricular surface.

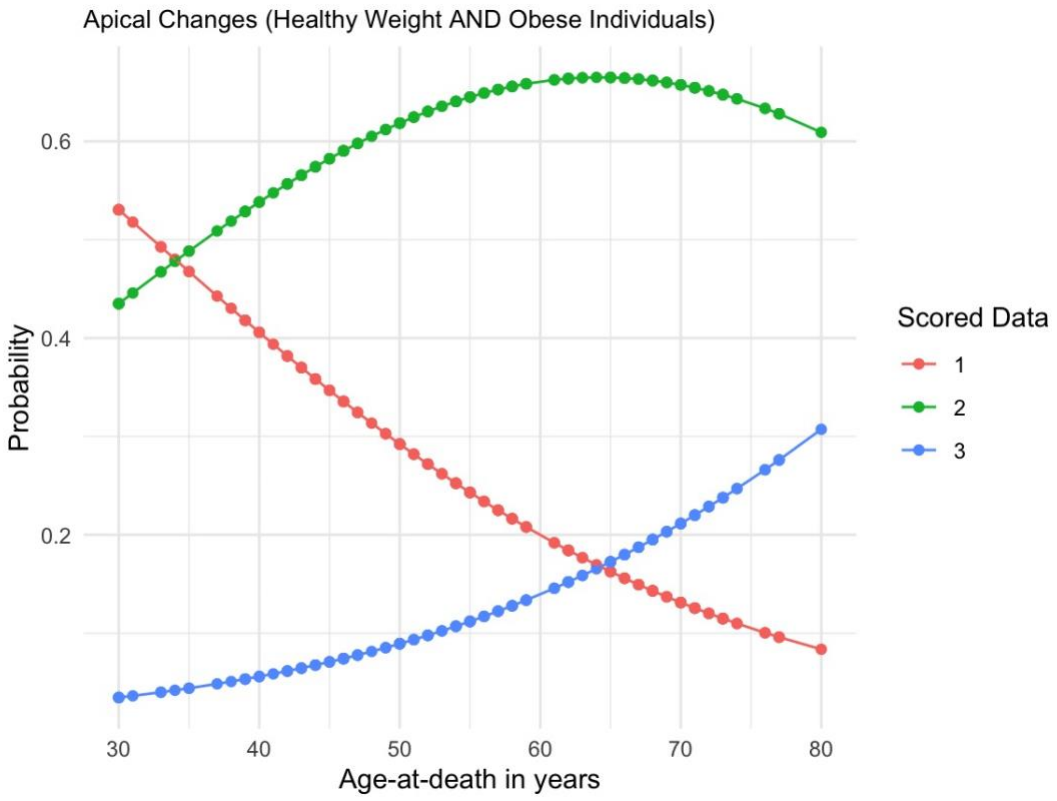

Figure 38: Scatterplot of an ordinal linear regression illustrating the probability of scaled scores assigned to an individual based on apical changes of the auricular surface.

The probability values listed on the y-axis in these figures indicate the likelihood that each assigned score is to occur at the age-at-death (x-axis). Both transverse organization (Fig. 34) and surface texture (Fig. 35) see the lower assigned scores decrease and higher assigned scores increases as age-at-death rises, which indicates that these two traits best reflect biological aging from auricular surface morphology.

5.5 Age Estimates and Age Stages

Table 26 highlights the statistical results based on the original criteria from the Buckberry and Chamberlain (2002) method. However, unlike Buckberry and Chamberlain (2002), this current study employs a 95% confidence interval based around the known age-at-death for the individuals in each of the auricular surface stages. Composite scores were separated into

individual scores rather than by sets of two in order to attempt to reduce the width of the age ranges as seen in Buckberry and Chamberlain (2002). As a result, the number of auricular surface stages in this current study increased.

Table 26: Age estimates from composite scores and age stages

Composite Score	Auricular Surface Stage	Number of Specimens	Mean Age	Standard Deviation	Median Age	Age Range	95% Confidence Interval
9	I	5	42.00	8.34	42	30-52	31.65, 52.35
10	II	16	44.44	10.89	43	30-70	38.63, 50.24
11	III	19	51.26	9.22	51	35-69	46.82, 55.70
12	IV	25	46.60	10.80	46	30-73	42.14, 51.06
13	V	32	58.94	9.94	62	34-74	55.35, 62.52
14	VI	23	59.26	12.66	58	33-80	53.78, 64.74
15	VII	19	67.11	6.65	67	54-77	63.90, 70.31
16	VIII	7	70.00	3.70	71	62-73	66.58, 73.42

17	IX	5	67.00	7.94	70	56-76	57.14, 76.86

6 DISCUSSION

This current study attempts to further understand the relationship between obesity and age-at-death estimation from auricular surface morphology. Due to the continuous rise of obesity rates in the United States in the last several decades (Fig. 2; CDC, 2023), accurately and effectively estimating age-at-death could assist in identification methods utilized in the field of forensic anthropology.

Previous studies discussing body mass and its relationship to the human skeleton have discovered that individuals with higher body mass exhibit more stress and pressure on the skeletal elements than those with less body weight. For example, obese individuals have been found to exhibit a greater amount of stress on their joints when walking than do those who possess less body mass (Berenbaum and Sellam, 2008; Browning and Kram, 2007; Wescott and Drew, 2015). In particular, the auricular surface, and the pelvis altogether, is more susceptible to morphological destruction due to its weight bearing responsibilities. Specifically, the auricular surface, or sacroiliac joint, assists in transferring weight from the spine to the lower extremities (Vleeming et al., 2012).

As the auricular surface is likely to experience greater levels of skeletal destruction, it was hypothesized that individuals exhibiting obese body mass index levels, or a BMI of 30.0 or greater, would be overestimated in terms of chronological age compared to their healthy weight counterparts, whose body mass index is defined to be between 18.5 and 24.9. In particular, I expected to discover higher rates of inaccuracy and bias, as well as greater total composite scores assigned to the auricular surfaces from the Buckberry and Chamberlain (2002) criteria in individuals exhibiting an obese body mass index level.

6.1 Body Mass Influences Between Inaccuracy and Composite Scores

Healthy weight individuals examined in this study were found to exhibit greater inaccuracy rates than their obese counterparts. However, the primary goal of this study is to determine if obese individuals are overestimated for age-at-death at a greater rate than those exhibiting a healthy weight body mass level. Thus, the bias values can potentially provide more insight. The obese cohort is found to exhibit a positive bias, while the healthy individuals possess a negative value for this statistic. In a similar study examining the influence of obesity on the auricular surface, Wescott and Drew (2015) discovered higher inaccuracy rate in their obese sample (10.20) rather than in the healthy weight cohort (6.49). Thus, it was unexpected to discover the opposite in my current research, despite healthy weight individuals only possessing a greater inaccurate rate by just over 1.0. However, my findings reflect a similarly theme for bias values to the findings by Wescott and Drew (2015). The pair discovered obese individuals to exhibit a bias of 4.45, while healthy weight counterparts possessed a bias of only 1.08. Another study conducted by Katherine Merritt (2017) discusses age-at-death estimation on individuals from various body mass levels using multiple aging methods. In this study, Merritt (2017) utilizes the Buckberry and Chamberlain (2002) criteria for auricular surface aging. Similar to findings from Wescott and Drew (2015), obese individuals were found to have slightly greater inaccuracy rates (11.88) compared to the healthy weight cohort (11.76); however, these are near identical values. When discussing bias, Merritt (2017) discovers similar findings to that of the current study as well as Wescott and Drew (2015). Obese individuals were found to exhibit a higher bias (9.19) than those with a healthy weight body mass (6.57). Thus, this current study supports previous findings that obese individuals are overestimated in terms of chronological age-at-death compared to healthy weight cohorts when examining values of bias.

Total composite scores between the healthy weight and obese groups essentially reflect the bias values between the two cohorts. Between the three age groups and biological sexes, healthy weight individuals did not exhibit greater mean values of total composite scores in any group. Only between the healthy and obese groups from the 50-64 years-of-age cohort did the two body mass levels exhibit identical composite score mean values (13). However, obese individuals exhibit higher overall scores in each of the other categories from the other two agree groups as well as both biological sexes.

6.2 Chronological Age-Related Differences Between Inaccuracy and Composite Scores

As illustrated in figures 16-24, linear regression was employed to determine the directionality of inaccuracy as body mass index increased, as well as the strength of the relationship between the two variables. In the regression for all individuals examined in this study, a positive correlation between inaccuracy and body mass was discovered. This indicates that as body mass increases, inaccuracy also increases, signifying that individuals with greater body weights are likely to be overestimated in chronological age than those who exhibit a lesser body mass. A similar theme was also discovered between each of the three age groups examined when the two body mass levels were examined simultaneously. However, differences occur when healthy weight and obese weight are analyzed independently. In these analyses, each linear regression excluding the 65-80 age group reveal that healthy weight individuals possess a more positive slope value than the obese cohort. Additionally, both the healthy weight and obese weight groupings exhibit positive slopes and correlation coefficients (r-values) in the 30-49, or "young" age group, and the 50-64, or "middle," cohort. However, the 65-80, or "old," age group exhibits negative slopes and correlation coefficients (r-values) for both body mass levels. Thus, these results imply that both the 30-49 and 50-64 age group are overestimated in terms of age

based on inaccuracy rates, while the 65-80 cohort is underestimated. The ANOVA between inaccuracy and body mass index levels reflect these findings, with the “young” and “old” cohorts exhibiting positive inaccuracy rates for both body mass levels, while the “old” age group possess negative values for both healthy weight and obese individuals.

These findings are confirmed by the total inaccuracy rates and bias values for each of the three age groups. Whereas inaccuracy measures how similar the estimated age is to the known age, bias is used to determine over- or underestimation of age in age-at-death estimation methods. The “young” age group exhibits the greatest bias value, the “middle” cohort the second greatest, and the individuals from the “old” grouping possess the lowest, and only negative, bias. These findings reveal that younger individuals are overestimated in their chronological age-at-death, while older individuals are underestimated regardless of body mass. In other words, as age increases into later life stages, individuals are likely to be underestimated in terms of age. Similar findings have been discovered in other studies on age-related changes to auricular surface morphology, including those that employ the Buckberry and Chamberlain (2002) method to estimate age-at-death from this feature (Hens and Belcastro, 2012: Rivera-Sandoval et al., 2018). Although I did expect the oldest individuals of this study to be underestimated for chronological age-at-death, it was shocking to discover the overall rate at which this occurred and at the bias value for the 65-80 age group. However, this substantial underestimation can be partially explained due to specific limitations of the Buckberry and Chamberlain (2002) scoring system, as well as constructing an age range for the “old” cohort that exceeded the parameters of the criteria from the same method used for auricular surface aging**.**

However, it is important to note that a majority of individuals exhibiting obese body mass levels exhibit higher, more positive rates of inaccuracy as well as overall composite scores

assigned from the Buckberry and Chamberlain (2002) scoring criteria. These results are also confirmed by both the t-tests and Mann-Whitney U tests between the healthy and obese cohorts for each of the three age groups. However, this trend is less significant when examining the "middle", or 50-64 age group. Unlike the "young" and "old" age cohorts, the 50-64 age group exhibits very similar rates of inaccuracy and total composite scores between healthy weight and obese weight individuals.

6.3 Sexual Dimorphism Between Inaccuracy and Composite Scores

Similar to the three age groups of 30-49, 50-64, and 65-80, both obese and healthy weight biological males and females were subject to various statistical analysis. Tests of linear regression when both body mass levels are examined independently reveal healthy weight individuals exhibit a stronger relationship between inaccuracy and body mass index levels than their obese counterparts. However, other statistical tests on inaccuracy and composite scores signify that the obese cohorts for both biological sexes possessed higher, or more positive, values than the healthy weight counterparts. These findings are further supported by the linear regressions examining both healthy and obese individuals simultaneously between both biological sexes. Thus, it can be stated that obese males and obese females were overestimated in terms of age-at-death compared to healthy weight males and healthy weight females, respectively. Differences were also present when males and females were examined where body mass levels were combined for each. Both the Kruskal-Wallis test for composite scores and the ANOVA for rates of inaccuracy indicate a significant difference exists between biological males and females in terms of age-at-death estimation, with males exhibiting greater overall values. Previous studies have discovered opposite results, with males and females not exhibiting significant levels of sexual dimorphism for chronological age-at-death based on morphological

changes of the auricular surface (Buckberry and Chamberlain, 2002; Hens et al., 2008; Wescott and Drew, 2015). However, the significant differences between the biological sexes in this current study can possibly be explained by the amount of fat content present between males and females. Biological females have been discovered to possess a greater proportion of body mass as fat (Power and Schulkin, 2008) to assist in ovulatory cycles and reproduction (Frisch, 1991). In addition, biological women are more likely to deposit fat on their lower extremities than their male counterparts (Power and Schulkin, 2008). Thus, higher fat content could potentially "protect" the auricular surface and other skeletal elements from a more rapid rate of morphological destruction.

6.4 Traits of the Buckberry and Chamberlain (2002) Scoring System

The plots of ordinal logistic regression between both body mass levels for the five traits utilized in scoring the auricular surface reflect the probability that each scored value will occur as chronological age increases. A trait can be determined to be more useful than another in estimating age-at-death based on if the maximum scores increase and minimum scores decrease with age. Microporosity is found to possess the greatest probability of a "3," the highest score possible, at 80 years-of-age, which is the maximum age-at-death in this study. A probability north of 0.80 is much greater than the second-greatest probability of any maximum score assigned. The trait with a maximum-score probability closest to that of microporosity is surface texture with a score of "4" possessing a probability slightly higher than 0.50 at 80 years-of-age. The scoring scale of surface texture is 1-5; however, no scores of "5" were assigned to an auricular surface in this study. A larger sample size would likely allow for scores of "5" to be witnessed more frequently, and I would expect this probability to be near or greater than that of the "3" of microporosity. However, both surface texture and transverse organization appear to be

the most impactful when estimating age-at-death from auricular surface morphology. At 80 years-of-age, both scores of "4" and "5," the two most maximum values from these two traits, possess probabilities of over 0.40. In addition, minimum scores in each of these two traits show continual decrease as chronological age increases, all the way to 80 years-of-age. Although microporosity expresses the greatest probability amongst its maximum score of "3," the value of "2" exhibits an extremely low probability of near 0.10. Thus, there are inconsistencies with this trait, and both surface texture and transverse organization are more impactful in estimating age from auricular surface morphology. Wescott and Drew (2015) also discover that both transverse organization and surface texture are effective in age-at-death estimation. Their findings reveal that transverse organization expresses the greatest correlation for the healthy, or normal, weight group (r_s = 0.51), while surface texture possesses the highest value for the obese cohort (r_s = 0.17) (Wescott and Drew, 2015).

6.5 Age Estimation Analysis Compared to Buckberry and Chamberlain (2002)

As illustrated in Table 26, statistical analysis performed on the known age-at-death and estimated ages differ from results found by Buckberry and Chamberlain (2002). In the current study, the mean ages exhibit a continuous rise as the auricular surface stage progresses in all but two of the stages. Although it should be expected for the mean ages to continue to increase in as the auricular surface stages progress, as in Buckberry and Chamberlain (2002), this decrease in the current research could be a result of separating the stages by individual composite scores. In addition, previous studies have also noted overlap between age ranges of the stages, as well as similar median and mean values, which also occurs in this current study (Falys et al., 2006; Hens and Belcastro, 2012). Thus, it can be understood as to why there are similarities between the results from this analysis in this current study. The lowest composite score of 9, as well as the

two highest scores of 16 and 17, in this research exhibit the narrowest age ranges. This can potentially be a result of the small samples size for each of these stages, as they represent the three stages with the least number of individuals. Increasing the sample size for each of these three stages could result in a clearer understanding on the true range of age-at-death for the respective composite scores. The values of standard deviation also differ from those calculated in Buckberry and Chamberlain (2002). In particular, the standard deviation values in this current study are greater in the lower composite scores and lower in the higher figures. However, the opposite appears to be true in the results from Buckberry and Chamberlain (2002). This could, once again, be due to two composite scores per stage, where the current study separates stages by one individual score. The 95% confidence intervals for each of the auricular surface stages can be beneficial for age-at-death determination in forensic casework as it represents the range at which age 95% of the sample is classified. These values are narrower than the overall age ranges for each of the stages, therefore allowing for a more concise and accurate age-at-death estimation.

6.6 Inaccuracy Outliers: Positive and Negative

As highlighted in Appendix G, inaccuracy values below -15.00 and above 15.00 were occasionally witnessed in this study. Individuals below and above these respective values were determined to be outliers, and thus additional analysis was conducted. 24 out of 151 (15.9%) individuals were deemed to be outliers. A majority of individuals with a value greater than 15.00 (8/12) were classified as overweight, while the remaining (4/12) exhibited healthy weight body mass index levels. These findings support other results of this current study in that obese individuals are more likely to be overestimated in terms of age-at-death than their healthy weight counterparts. When examining the negative outliers, or individuals with an inaccuracy rate below

-15.00, almost all (10/12) belong to those with healthy weights rather than those classified as obese (2/12). This is further evidence that healthy weight individuals are typically underestimated for chronological age than those with an obese body mass index level. Although outliers of inaccuracy may limit the applicability of this age-at-death estimation method, Buckberry and Chamberlain (2002) experienced a wide range of age-at-deaths for each stage of the auricular surface and composite score. (Table 3). Thus, it can be possible to occasionally examine an individual that is an outlier in terms of estimated age.

6.7 Study Limitations

Various limitations exist in the current framework of this study that must be considered. For example, physical activity levels of the individuals examined in this research were not provided, primarily because these details were not included as a focus of this study. Previous research indicates that increased physical and occupational activity can impact skeletal morphology (Branca, 2017; Merritt, 2017). Thus, this information could potentially allow for a clearer understanding of the results from this current study. Another area of this research that is unknown is at what stage in the life cycle did the individuals examined become classified as exhibiting obese body mass or healthy weight. The time of the life cycle in which an individual became obese or began to exhibit healthy weight can significantly impact how the life history is reflected in auricular surface morphology. Furthermore, although the Buckberry and Chamberlain (2002) scoring system has been determined to be an effective method to estimate age-at-death from the auricular surface, the use of the mean ages could potentially, and has, skewed results, such as in the 65-80 age group in this current study. For instance, the highest mean age presented in the Buckberry and Chamberlain (2002) method is 72.25 and corresponds with the greatest composite score stage of 17-19. Thus, if mean ages are being used as an

estimated age to compare with actual age-at-death, any individual over the age of 72 years is automatically going to be underestimated. Buckberry (2015) discusses this dilemma, and states that individual-specific age ranges and/or probability densities should be favored over mean ages when estimating age-at-death.

6.8 Future Steps and Directions

This study aims to advance the understanding of the influence of obesity on age-at-death estimation from auricular surface morphology. However, steps can be taken in future studies to further determine this relationship. For example, employing a greater sample size can be beneficial in order to understand how obesity affects more individuals than are examined in this current study. In addition, it can be valuable to examine individuals from all four body mass index levels set by the CDC rather than just healthy weight and obese. By including both underweight and overweight individuals in future research, it can be more accurately determined if individuals are over- or underestimated as body mass increases. Furthermore, examining various age-at-death indicators, such as the pubic symphysis, sternal end of the right fourth rib, and others, in conjunction with the auricular surface can result in more accurate estimations for chronological age. Although the sacroiliac joint has been deemed to be effective in age-at-death determination when examined independently, employing multiple skeletal elements at once in age estimation can improve accuracy levels.

7 CONCLUSION

As rates of obesity have significantly increased in the last four to five decades, understanding the relationship between increased body mass index levels and age-at-death estimation is significant to the field of forensic anthropology. This current study tested the influence of obesity on age-at-death estimation from the auricular surface of the os coxae from a sample of 151 individuals between three age categories (30-49, 50-64, 65-80) from both biological sexes. Particularly, this research attempted to build-on previous studies on this topic, such as Drew (2010), Merritt (2017), and Wescott and Drew (2015), to determine if obese individuals were over-aged, under-aged, or accurately aged based on auricular surface morphology. The Buckberry and Chamberlain (2002) method was used on all individuals in order to provide a composite score to each auricular surface. The individual was then assigned an expected age based upon the mean age derived from the assigned composite score, and this figure was then compared with the actual age at the time of death. It can ultimately be determined that obesity influences age-at-death estimation based on auricular surface morphology through overestimation compared to healthy weight individuals. Obese individuals exhibit higher rates of inaccuracy and total composite scores compared to their healthy weight counterparts. Obese individuals were also discovered to exhibit higher inaccuracy rates in each of the three age groups, and in two out of the three age cohorts when composite scores were compared. The one exception, the “middle,” or 50-64 age group, expressed identical mean composite scores between both healthy weight and obese individuals. In both biological males and females, the obese cohort exhibits greater inaccuracy and total composite scores than the healthy weights. These findings support previous research that sexual dimorphism exists between the two biological sexes in age-at-death estimation from the auricular surface, while also

disagreeing with other studies that have stated that no substantial differences between the biological sexes are present. However, further studies with potentially larger sample sizes are needed to fully understand the influence of obesity on morphological change of the auricular surface. In addition, future studies examining how obesity impacts other skeletal aging indicators, such as the pubic symphysis, sternal end of the right fourth rib, and others can illustrate how obesity influences age-at-death estimation across the body. This will allow for a more detailed understanding of obesity's influence on the human skeleton, which will assist forensic anthropologists in future cases where age-at-death estimation is needed.

APPENDICES

Appendix A

UTID (30-49)	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT88-16D	Female	3	2	2	3	2	12	51.41	29-81	30	21.41	23.4	Healthy/Normal
UT62-16D	Female	3	1	2	2	1	9	37.86	16-65	30	7.86	22.9	Healthy/Normal
UT54-09	Male	2	3	2	2	1	10	37.86	16-65	30	7.86	22	Healthy/Normal
UT62-13D	Male	3	2	2	2	1	10	37.86	16-65	30	7.86	20.9	Healthy/Normal
UT54-09D	Male	4	4	2	1	1	12	51.41	29-81	30	21.41	21.6	Healthy/Normal
UT40-08D	Female	3	2	2	2	1	10	37.86	16-65	33	4.86	20.6	Healthy/Normal
UT04-10D	Male	3	3	2	2	1	11	51.41	29-81	35	16.41	23.6	Healthy/Normal
UT74-05	Male	2	3	1	2	3	10	37.86	16-65	38	-0.14	24	Healthy/Normal
UT33-02D	Male	2	2	2	1	3	10	37.86	16-65	39	-1.14	23.7	Healthy/Normal
UT88-10D	Female	2	2	2	2	1	9	37.86	16-65	39	-1.14	19.1	Healthy/Normal
UT33-10D	Male	3	2	2	2	1	10	37.86	16-65	40	-2.14	23.7	Healthy/Normal
UT36-05	Male	2	3	3	2	2	13	59.94	29-88	41	18.94	22	Healthy/Normal
UT52-15D	Male	3	2	1	2	2	10	37.86	16-65	42	-4.14	20.8	Healthy/Normal
UT36-18D	Female	3	2	1	2	1	9	37.86	16-65	42	-4.14	20.2	Healthy/Normal
UT09-00	Female	4	2	3	2	1	12	51.41	29-81	43	8.41	23	Healthy/Normal
UT06-06	Male	2	3	1	2	2	10	37.86	16-65	43	-5.14	20	Healthy/Normal
UT69-06D	Female	3	2	2	2	1	10	37.86	16-65	45	-7.14	23.3	Healthy/Normal
UT113-10D	Female	4	2	2	2	2	12	51.41	29-81	45	6.41	24.3	Healthy/Normal
UT93-17D	Female	3	3	2	2	1	11	51.41	29-81	46	5.41	24	Healthy/Normal
UT35-07	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	22	Healthy/Normal
UT11-11D	Female	3	2	2	1	2	10	37.86	16-65	46	-8.14	23.6	Healthy/Normal
UT02-06	Male	2	3	1	2	1	11	51.41	29-81	47	4.41	23	Healthy/Normal
UT92-05D	Female	2	3	1	2	1	9	37.86	16-65	47	-9.14	24.4	Healthy/Normal
UT79-18D	Female	3	3	3	2	3	14	59.94	29-88	49	10.94	21.3	Healthy/Normal
UT26-03	Male	2	3	2	2	2	12	51.41	29-81	49	2.41	20	Healthy/Normal
UTID (50-64)													
UT08-11D	Female	3	3	1	3	2	12	51.41	29-81	50	1.41	21.3	Healthy/Normal
UT49-08	Male	3	3	1	3	2	12	51.41	29-81	50	1.41	22	Healthy/Normal
UT64-10D	Female	4	3	2	2	2	13	59.94	29-88	50	9.94	20.6	Healthy/Normal
UT85-06D	Male	5	3	2	2	2	14	59.94	29-88	50	9.94	23.7	Healthy/Normal
UT58-06D	Female	3	2	2	3	1	11	51.41	29-81	51	0.41	22.5	Healthy/Normal
UT64-05	Male	4	3	3	2	1	13	59.94	29-88	51	8.94	19.9	Healthy/Normal
UT33-03D	Female	4	2	2	2	2	12	51.41	29-81	51	0.41	20	Healthy/Normal
UT107-08D	Female	3	2	1	2	1	9	37.86	16-65	52	-14.14	18.9	Healthy/Normal
UT78-05	Male	3	2	2	3	2	12	51.41	29-81	53	-1.59	19	Healthy/Normal
UT32-13D	Female	3	3	2	2	2	12	51.41	29-81	53	-1.59	24.3	Healthy/Normal
UT11-04D	Female	4	3	1	2	1	11	51.41	29-81	54	-2.59	23	Healthy/Normal
UT04-93	Male	4	4	2	3	2	15	66.71	39-91	54	12.71	24	Healthy/Normal
UT21-07	Male	4	3	3	2	1	13	59.94	29-88	54	5.94	23	Healthy/Normal
UT83-05	Male	4	4	2	2	2	14	59.94	29-88	54	5.94	23	Healthy/Normal
UT48-15D	Female	4	3	1	3	1	11	51.41	29-81	55	-3.79	20.9	Healthy/Normal
UT42-06D	Female	3	2	1	2	2	10	37.86	16-65	56	-18.14	23.6	Healthy/Normal
UT18-07	Male	4	3	2	3	2	14	59.94	29-88	56	3.94	24	Healthy/Normal
UT06-05	Male	5	4	3	3	2	17	72.25	53-92	56	16.25	23	Healthy/Normal
UT08-04	Male	4	4	1	3	2	14	59.94	29-88	57	2.94	22	Healthy/Normal
UT08-07D	Female	4	3	2	3	2	14	59.94	29-88	57	2.94	24.7	Healthy/Normal
UT10-17D	Female	4	2	1	2	2	11	51.41	29-81	58	-6.59	22.6	Healthy/Normal
UT29-03D	Female	3	2	1	3	1	10	37.86	16-65	59	-21.14	18.5	Healthy/Normal
UT16-00	Male	4	4	1	3	2	14	59.94	29-88	61	-1.06	21	Healthy/Normal
UT37-05	Male	4	2	2	3	2	13	59.94	29-88	62	-2.06	24	Healthy/Normal
UT05-03	Male	5	4	2	3	3	17	72.25	53-92	62	10.25	21	Healthy/Normal

UTID (65-80)													
UT45-11D	Female	3	2	1	2	3	11	51.41	29-81	65	-13.59	23.6	Healthy/Normal
UT47-05D	Male	3	3	2	3	2	13	59.94	29-88	65	-5.06	19.9	Healthy/Normal
UT20-02D	Male	4	3	2	3	1	13	59.94	29-88	65	-5.06	22.1	Healthy/Normal
UT30-14D	Male	4	3	2	2	2	13	59.94	29-88	65	-5.06	23.7	Healthy/Normal
UT48-19D	Male	5	3	1	3	3	15	66.71	39-91	66	0.71	22.6	Healthy/Normal
UT43-02D	Male	4	4	2	3	2	15	66.71	39-91	66	0.71	21.3	Healthy/Normal
UT105-07D	Female	3	3	2	3	3	14	59.94	29-88	68	-8.06	23.4	Healthy/Normal
UT16-12D	Female	4	2	1	2	2	11	51.41	29-81	68	-16.59	21.6	Healthy/Normal
UT92-16D	Female	3	3	2	3	2	13	59.94	29-88	68	-8.06	22.8	Healthy/Normal
UT50-15D	Male	4	4	2	2	1	13	59.94	29-88	68	-8.06	22.1	Healthy/Normal
UT38-17D	Female	4	3	2	3	1	13	59.94	29-88	69	-9.06	18.6	Healthy/Normal
UT29-09D	Male	4	4	1	2	2	13	59.94	29-88	69	-9.06	20.2	Healthy/Normal
UT63-17D	Male	5	2	1	2	2	11	51.41	29-81	69	-17.59	23	Healthy/Normal
UT94-09D	Male	4	4	2	3	3	16	66.71	39-91	70	-3.29	18.7	Healthy/Normal
UT21-16D	Female	2	3	1	3	1	10	37.86	16-65	70	-32.14	18.9	Healthy/Normal
UT95-16D	Female	5	3	2	2	1	13	59.94	29-88	70	-10.06	23.9	Healthy/Normal
UT104-17D	Female	4	3	2	2	2	13	59.94	29-88	71	-11.06	22.2	Healthy/Normal
UT19-05D	Male	5	3	2	2	2	14	59.94	29-88	71	-11.06	21.9	Healthy/Normal
UT05-04D	Male	5	2	1	3	2	13	59.94	29-88	72	-12.06	21.9	Healthy/Normal
UT43-04D	Male	4	4	3	3	2	16	66.71	39-91	72	-5.29	19.1	Healthy/Normal
UT71-09D	Male	4	4	1	3	2	15	66.71	39-91	73	-6.29	20.7	Healthy/Normal
UT109-10D	Female	4	2	2	3	1	12	51.41	29-81	73	-21.59	22.1	Healthy/Normal
UT20-17D	Female	5	3	2	3	2	15	66.71	39-91	74	-7.29	21.9	Healthy/Normal
UT02-05D	Female	4	2	3	2	3	14	59.94	29-88	76	-16.06	21	Healthy/Normal
UT82-17D	Female	5	4	2	2	1	14	59.94	29-88	77	-17.06	21	Healthy/Normal
UT15-09D	Female	4	3	3	3	2	15	66.71	39-91	77	-9.29	23	Healthy/Normal
UT11-12D	Male	4	3	2	3	2	14	59.94	29-88	80	-20.06	21.9	Healthy/Normal

Appendix 1: All individuals examined in this study sorted by healthy weight body mass.

Appendix B

UTID (30-49)	M/F	T.O	S.T.	Macro	Micro	A.C.	**Total**	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT55-17D	Male	3	3	2	2	2	12	51.41	29-81	31	20.41	36	Obesity
UT24-09D	Male	5	3	2	2	2	14	59.94	29-88	33	26.94	40.7	Obesity
UT57-09D	Female	4	3	2	2	2	13	59.94	29-88	34	25.94	39.2	Obesity
UT38-10D	Male	3	3	3	2	1	12	51.41	29-81	35	16.41	38	Obesity
UT107-07	Male	4	3	1	2	2	12	51.41	29-81	37	14.41	37	Obesity
UT44-04D	Male	3	3	2	2	2	12	51.41	29-81	39	12.41	38	Obesity
UT32-06D	Female	4	2	2	2	1	11	51.41	29-81	39	12.41	51.5	Obesity
UT60-12D	Female	3	2	2	2	1	10	37.86	16-65	40	-2.14	32.3	Obesity
UT25-04	Male	4	4	2	2	2	14	59.94	29-88	40	19.94	34	Obesity
UT49-09D	Female	4	3	1	2	2	12	51.41	29-81	42	9.41	41.6	Obesity
UT74-06D	Female	4	2	1	3	1	11	51.41	29-81	42	9.41	35.5	Obesity
UT37-03D	Male	3	3	3	2	3	14	59.94	29-88	43	16.94	31.9	Obesity
UT89-07	Male	4	3	2	2	3	14	59.94	29-88	43	16.94	32	Obesity
UT34-05D	Male	3	2	3	2	2	12	51.41	29-81	44	7.41	37.2	Obesity
UT114-07D	Male	4	3	2	2	1	12	51.41	29-81	44	7.41	35.9	Obesity
UT49-06	Male	3	2	2	3	2	12	51.41	29-81	44	7.41	31	Obesity
UT51-07D	Female	3	3	2	3	2	13	59.94	29-88	44	15.94	37.8	Obesity
UT82-13D	Female	3	2	1	2	2	10	37.86	16-65	45	-7.14	51.4	Obesity
UT21-06	Male	3	3	2	2	2	12	51.41	29-81	46	5.41	31	Obesity
UT85-11D	Female	3	2	2	2	2	11	51.41	29-81	46	5.41	44.9	Obesity
UT62-11D	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	34	Obesity
UT81-08D	Female	4	2	2	3	1	12	51.41	29-81	46	5.41	30	Obesity
UT87-10D	Female	4	2	1	2	2	11	51.41	29-81	46	5.41	33.6	Obesity
UT75-06	Male	4	4	1	2	2	13	59.94	29-88	47	12.94	33	Obesity
UT128-09D	Female	4	3	1	2	3	12	51.41	29-81	48	3.41	35.2	Obesity
UTID (50-64)													
UT14-03D	Male	4	3	2	2	2	13	59.94	29-88	50	9.94	31	Obesity
UT61-04D	Male	5	3	1	2	2	13	51.41	29-81	50	1.41	36.3	Obesity
UT10-07D	Female	4	4	2	2	1	13	59.94	29-88	50	9.94	35	Obesity
UT39-03D	Female	3	2	1	2	3	11	51.41	29-81	52	-0.59	32.9	Obesity
UT31-13D	Female	4	3	2	2	2	13	59.94	29-88	52	7.94	30.1	Obesity
UT62-09D	Female	3	3	2	2	2	12	51.41	29-81	52	-0.59	35.5	Obesity
UT54-05D	Female	3	2	2	2	2	11	51.41	29-81	54	-2.59	30.8	Obesity
UT61-05D	Female	4	1	2	1	2	10	37.86	16-65	55	-17.14	31.1	Obesity
UT72-08D	Female	4	2	1	2	2	11	51.41	29-81	55	-3.59	42	Obesity
UT69-05D	Male	4	2	2	3	2	13	59.94	29-88	55	4.94	43.1	Obesity
UT95-10D	Male	4	4	2	3	2	15	66.71	39-91	55	11.71	30.4	Obesity
UT84-11D	Male	4	3	1	3	2	13	59.94	29-88	55	4.94	31.9	Obesity
UT87-11D	Female	4	3	1	2	2	12	59.94	29-88	57	2.94	30.9	Obesity
UT100-06D	Female	4	3	2	3	2	15	66.71	39-91	57	9.71	37.1	Obesity
UT17-05D	Female	4	3	2	2	2	13	59.94	29-88	58	1.94	39.8	Obesity
UT15-06D (right)	Female	5	2	2	2	3	14	59.94	29-88	58	1.94	40.3	Obesity
UT67-05D	Male	4	3	2	3	2	14	59.94	29-88	58	1.94	44.2	Obesity
UT50-11D	Male	4	3	2	3	2	14	59.94	29-88	59	0.94	33.2	Obesity
UT03-05D	Male	4	4	2	3	1	14	59.94	29-88	59	0.94	31	Obesity
UT32-17D	Female	4	3	1	2	2	13	59.94	29-88	61	-1.06	34.9	Obesity
UT70-13D	Female	3	3	3	2	2	13	59.94	29-88	62	-2.06	43.2	Obesity
UT44-10D	Female	4	3	2	2	2	13	59.94	29-88	62	-2.06	40.2	Obesity
UT50-03D	Male	3	3	2	3	2	13	59.94	29-88	62	-2.06	38.7	Obesity
UT26-12D	Male	5	4	2	3	2	16	66.71	39-91	62	4.71	31.1	Obesity
UT14-19D	Female	4	3	1	3	2	13	59.94	29-88	63	-3.06	30.3	Obesity
UT51-03D	Male	4	3	2	3	3	15	66.71	39-91	63	3.71	44.3	Obesity
UT32-02D	Male	4	4	2	3	2	15	66.71	39-91	64	2.71	38.9	Obesity
UTID (65-80)													
UT69-15D	Female	5	3	2	3	2	15	66.71	39-91	66	0.71	30.1	Obesity
UT45-13D	Male	5	3	2	3	2	15	66.71	39-91	66	0.71	33.1	Obesity
UT27-17D	Male	3	3	2	3	2	13	59.94	29-88	67	-7.06	30.7	Obesity
UT07-07	Female	4	4	3	3	2	15	66.71	39-91	67	-0.29	31	Obesity
UT14-18D	Female	4	4	2	3	2	15	66.71	39-91	67	-0.29	39.2	Obesity
UT41-04	Male	4	3	2	2	3	14	59.94	29-88	68	-8.06	30	Obesity
UT31-93	Male	4	3	3	3	2	15	66.71	39-91	68	-1.29	33	Obesity
UT38-01D	Male	4	4	3	3	3	17	72.25	53-92	70	2.25	30.5	Obesity
UT56-03	Male	5	4	2	3	2	16	66.71	39-91	70	-3.29	37	Obesity
UT30-03	Male	4	4	3	3	3	16	66.71	39-91	71	-4.29	34	Obesity
UT07-06	Male	4	4	2	3	2	15	66.71	39-91	71	-4.29	40	Obesity
UT39-05 (RIGHT)	Male	5	4	2	3	3	17	72.25	53-92	71	1.25	37	Obesity
UT20-06	Female	4	4	3	2	2	15	66.71	39-91	71	-4.29	38	Obesity
UT19-00	Female	4	4	3	3	3	16	66.71	39-91	72	-5.29	36	Obesity
UT62-04D	Female	3	3	1	3	2	12	51.41	29-81	73	-21.59	35.9	Obesity
UT32-04	Female	3	4	3	3	2	14	59.94	29-88	73	-13.06	32	Obesity
UT45-03	Female	4	3	3	3	2	15	66.71	39-91	73	-6.29	34	Obesity
UT96-06	Female	4	3	3	3	2	14	59.94	29-88	73	-13.06	35	Obesity
UT81-11D	Male	5	4	2	3	2	16	66.71	39-91	73	-6.29	34.7	Obesity
UT13-05	Female	3	3	3	3	2	13	59.94	29-88	74	-14.06	40	Obesity
UT26-11D	Female	5	4	3	3	2	17	72.25	53-92	76	-3.75	33.8	Obesity
UT06-18D	Female	4	4	3	3	2	15	66.71	39-91	77	-10.29	30.9	Obesity

Appendix 2: All individuals examined in this study sorted by obese body mass.

Appendix C

UTID (All Males)	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT62-13D	Male	3	2	2	2	1	10	37.86	16-65	30	7.86	20.9	Healthy/Normal
UT54-09D	Male	2	3	2	2	1	10	37.86	16-65	30	7.86	21.6	Healthy/Normal
UT04-10D	Male	3	3	2	2	1	11	51.41	29-81	35	16.41	23.6	Healthy/Normal
UT33-02D	Male	2	2	2	1	3	10	37.86	16-65	39	-1.14	23.7	Healthy/Normal
UT33-10D	Male	3	2	2	2	1	10	37.86	21-38	40	-2.14	23.7	Healthy/Normal
UT52-15D	Male	3	2	1	2	2	10	37.86	16-65	42	-4.14	20.8	Healthy/Normal
UT06-06	Male	2	3	1	2	2	10	37.86	16-65	43	-5.14	20	Healthy/Normal
UT36-05	Male	2	3	3	2	2	13	59.94	29-88	41	18.94	22	Healthy/Normal
UT02-06	Male	2	3	1	2	1	11	51.41	29-81	47	4.41	23	Healthy/Normal
UT74-05	Male	2	3	1	2	3	10	37.86	16-65	38	-0.14	24	Healthy/Normal
UT26-03	Male	2	3	2	2	2	12	51.41	29-81	49	2.41	20	Healthy/Normal
UT54-09	Male	2	3	2	2	1	10	37.86	16-65	30	7.86	22	Healthy/Normal
UT55-17D	Male	3	3	2	2	2	12	51.41	29-81	31	20.41	36	Obesity
UT24-09D	Male	5	3	2	2	2	14	59.94	29-88	33	26.94	40.7	Obesity
UT38-10D	Male	3	3	3	2	1	12	51.41	29-81	35	16.41	38	Obesity
UT44-04D	Male	3	3	2	2	2	12	51.41	29-81	39	12.41	38	Obesity
UT37-03D	Male	3	3	3	2	3	14	59.94	29-88	43	16.94	31.9	Obesity
UT34-05D	Male	3	2	3	2	2	12	51.41	29-81	44	7.41	37.2	Obesity
UT114-07D	Male	4	3	2	2	1	12	51.41	29-81	44	7.41	35.9	Obesity
UT49-06	Male	3	2	2	3	2	12	51.41	29-81	44	7.41	31	Obesity
UT89-07	Male	4	3	2	2	3	14	59.94	29-88	43	16.94	32	Obesity
UT25-04	Male	4	4	2	2	2	14	59.94	29-88	40	19.94	34	Obesity
UT75-06	Male	4	4	1	2	2	13	59.94	29-88	47	12.94	33	Obesity
UT21-06	Male	3	3	2	2	2	12	51.41	29-81	46	5.41	31	Obesity
UT107-07	Male	4	3	1	2	2	12	51.41	29-81	37	14.41	37	Obesity
UT85-06D	Male	5	3	2	2	2	14	59.94	29-88	50	9.94	23.7	Healthy/Normal
UT08-04	Male	4	4	1	3	2	14	59.94	29-88	57	2.94	22	Healthy/Normal
UT21-07	Male	4	3	3	2	1	13	59.94	29-88	54	5.94	23	Healthy/Normal
UT83-05	Male	4	4	2	2	2	14	59.94	29-88	54	5.94	23	Healthy/Normal
UT18-07	Male	4	3	2	3	2	14	59.94	29-88	56	3.94	24	Healthy/Normal
UT04-93	Male	4	4	2	3	2	15	66.71	39-91	54	12.71	24	Healthy/Normal
UT37-05	Male	4	2	2	3	2	13	59.94	29-88	62	-2.06	24	Healthy/Normal
UT78-05	Male	3	2	2	3	2	12	51.41	29-81	53	-1.59	19	Healthy/Normal
UT16-00	Male	4	4	1	3	2	14	59.94	29-88	61	-1.06	21	Healthy/Normal
UT05-03	Male	5	4	2	3	3	17	72.25	53-92	62	10.25	21	Healthy/Normal
UT49-08	Male	3	3	1	3	2	12	51.41	29-81	50	1.41	22	Healthy/Normal
UT06-05	Male	5	4	3	3	2	17	72.25	53-92	56	16.25	23	Healthy/Normal
UT64-05	Male	4	3	3	2	1	13	59.94	29-88	51	8.94	19.9	Healthy/Normal
UT69-05D	Male	4	2	2	3	2	13	59.94	29-88	55	4.94	43.1	Obesity
UT95-10D	Male	4	4	2	3	2	15	66.71	39-91	55	11.71	30.4	Obesity
UT84-11D	Male	4	3	1	3	2	13	59.94	29-88	55	4.94	31.9	Obesity
UT67-05D	Male	4	3	2	3	2	14	59.94	29-88	58	1.94	44.2	Obesity
UT50-11D	Male	4	3	2	3	2	14	59.94	29-88	59	0.94	33.2	Obesity
UT03-05D	Male	4	4	2	3	1	14	59.94	29-88	59	0.94	31	Obesity
UT50-03D	Male	3	3	2	3	2	13	59.94	29-88	62	-2.06	38.7	Obesity
UT26-12D	Male	5	4	2	3	2	16	66.71	39-91	62	4.71	31.1	Obesity
UT51-03D	Male	4	3	2	3	3	15	66.71	39-91	63	3.71	44.3	Obesity
UT32-02D	Male	4	4	2	3	2	15	66.71	39-91	64	3.71	38.9	Obesity
UT14-03D	Male	4	3	2	2	2	13	59.94	29-88	50	9.94	31	Obesity
UT61-04D	Male	5	3	1	2	2	13	51.41	29-81	50	1.41	36.3	Obesity
UT11-12D	Male	4	3	2	3	2	14	59.94	29-88	80	-20.06	21.9	Healthy/Normal
UT47-05D	Male	3	3	2	3	2	13	59.94	29-88	65	-5.06	19.9	Healthy/Normal
UT20-02D	Male	4	3	2	3	1	13	59.94	29-88	65	-5.06	22.1	Healthy/Normal
UT30-14D	Male	4	3	2	2	2	13	59.94	29-88	65	-5.06	23.7	Healthy/Normal
UT48-19D	Male	5	3	1	3	3	15	66.71	39-91	66	0.71	22.6	Healthy/Normal
UT43-02D	Male	4	4	2	3	2	15	66.71	39-91	66	0.71	21.3	Healthy/Normal
UT50-15D	Male	4	4	2	2	1	13	59.94	29-88	68	-8.06	22.1	Healthy/Normal
UT29-09D	Male	4	4	1	2	2	13	59.94	29-88	69	-9.06	20.2	Healthy/Normal
UT63-17D	Male	5	2	1	2	2	11	51.41	29-81	69	-17.59	23	Healthy/Normal
UT94-09D	Male	4	4	2	3	3	16	72.25	53-92	70	2.25	18.7	Healthy/Normal
UT19-05D	Male	5	3	2	2	2	14	59.94	29-88	71	-11.06	21.9	Healthy/Normal
UT05-04D	Male	5	2	1	3	2	13	59.94	29-88	72	-12.06	21.9	Healthy/Normal
UT43-04D	Male	4	4	3	3	2	16	72.25	53-92	72	0.25	19.1	Healthy/Normal
UT71-09D	Male	4	4	1	3	2	15	66.71	39-91	73	-6.29	20.7	Healthy/Normal
UT45-13D	Male	5	3	2	3	2	15	66.71	39-91	66	0.71	33.1	Obesity
UT27-17D	Male	3	3	2	3	2	13	59.94	29-88	67	-7.06	30.7	Obesity
UT38-01D	Male	4	4	3	3	3	17	72.25	53-92	70	2.25	30.5	Obesity
UT81-11D	Male	5	4	2	3	2	16	72.25	53-92	73	-0.75	34.7	Obesity
UT41-04	Male	4	3	2	2	3	14	59.94	29-88	68	-8.06	30	Obesity
UT31-93	Male	4	3	3	3	2	15	66.71	39-91	68	-1.29	33	Obesity
UT30-03	Male	4	4	3	3	3	16	72.25	53-92	71	1.25	34	Obesity
UT56-03	Male	5	4	2	3	2	16	66.71	39-91	70	-3.29	37	Obesity
UT07-06	Male	4	4	2	3	2	15	66.71	39-91	71	-4.29	40	Obesity
UT39-05 (RIGHT)	Male	5	4	2	3	3	17	72.25	53-92	71	1.25	37	Obesity

Appendix 3: All males examined in this study sorted by healthy weight and obese body mass between the 30-49, 50-64, and 65-80 age groups.

Appendix D

UTID (All Males by Age)	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT62-13D	Male	3	2	2	2	1	10	37.86	16-65	30	7.86	20.9	Healthy/Normal
UT54-09	Male	2	3	2	2	1	10	37.86	16-65	30	7.86	22	Healthy/Normal
UT54-09D	Male	2	3	2	2	1	10	37.86	16-65	30	7.86	21.6	Healthy/Normal
UT55-17D	Male	3	3	2	2	2	12	51.41	29-81	31	20.41	36	Obesity
UT24-09D	Male	5	3	2	2	2	14	59.94	29-88	33	26.94	40.7	Obesity
UT38-10D	Male	3	3	3	2	1	12	51.41	29-81	35	16.41	38	Obesity
UT107-07	Male	4	3	1	2	2	12	51.41	29-81	37	14.41	37	Obesity
UT04-10D	Male	3	3	2	2	1	11	51.41	29-81	35	16.41	23.6	Healthy/Normal
UT74-05	Male	2	3	1	2	3	10	37.86	16-65	38	-0.14	24	Healthy/Normal
UT44-04D	Male	3	3	2	2	2	12	51.41	29-81	39	12.41	38	Obesity
UT33-02D	Male	2	2	2	1	3	10	37.86	16-65	39	-1.14	23.7	Healthy/Normal
UT25-04	Male	4	4	2	2	2	14	59.94	29-88	40	19.94	34	Obesity
UT33-10D	Male	3	2	2	2	1	10	37.86	21-38	40	-2.14	23.7	Healthy/Normal
UT36-05	Male	2	3	3	2	2	13	59.94	29-88	41	18.94	22	Healthy/Normal
UT52-15D	Male	3	2	1	2	2	10	37.86	16-65	42	-4.14	20.8	Healthy/Normal
UT89-07	Male	4	3	2	2	3	14	59.94	29-88	43	16.94	32	Obesity
UT37-03D	Male	3	3	3	2	3	14	59.94	29-88	43	16.94	31.9	Obesity
UT06-06	Male	2	3	1	2	2	10	37.86	16-65	43	-5.14	20	Healthy/Normal
UT34-05D	Male	3	2	3	2	2	12	51.41	29-81	44	7.41	37.2	Obesity
UT114-07D	Male	4	3	2	2	1	12	51.41	29-81	44	7.41	35.9	Obesity
UT49-06	Male	3	2	2	3	2	12	51.41	29-81	44	7.41	31	Obesity
UT21-06	Male	3	3	2	2	2	12	51.41	29-81	46	5.41	31	Obesity
UT75-06	Male	4	4	1	2	2	13	59.94	29-88	47	12.94	33	Obesity
UT02-06	Male	2	3	1	2	1	11	51.41	29-81	47	4.41	23	Healthy/Normal
UT26-03	Male	2	3	2	2	2	12	51.41	29-81	49	2.41	20	Healthy/Normal
UT47-05D	Male	3	3	2	3	2	13	59.94	29-88	65	-5.06	19.9	Healthy/Normal
UT20-02D	Male	4	3	2	3	1	13	59.94	29-88	65	-5.06	22.1	Healthy/Normal
UT30-14D	Male	4	3	2	2	2	13	59.94	29-88	65	-5.06	23.7	Healthy/Normal
UT48-19D	Male	5	3	1	3	3	15	66.71	39-91	66	0.71	22.6	Healthy/Normal
UT43-02D	Male	4	4	2	3	2	15	66.71	39-91	66	0.71	21.3	Healthy/Normal
UT45-13D	Male	5	3	2	3	2	15	66.71	39-91	66	0.71	33.1	Obesity
UT27-17D	Male	3	3	2	3	2	13	59.94	29-88	67	-7.06	30.7	Obesity
UT50-15D	Male	4	4	2	2	1	13	59.94	29-88	68	-8.06	22.1	Healthy/Normal
UT41-04	Male	4	3	2	2	3	14	59.94	29-88	68	-8.06	30	Obesity
UT31-93	Male	4	3	3	3	2	15	66.71	39-91	68	-1.29	33	Obesity
UT29-09D	Male	4	4	1	2	2	13	59.94	29-88	69	-9.06	20.2	Healthy/Normal
UT63-17D	Male	5	2	1	2	2	11	51.41	29-81	69	-17.59	23	Healthy/Normal
UT38-01D	Male	4	4	3	3	3	17	72.25	53-92	70	2.25	30.5	Obesity
UT56-03	Male	5	4	2	3	2	16	66.71	39-91	70	-3.29	37	Obesity
UT94-09D	Male	4	4	2	3	3	16	72.25	53-92	70	2.25	18.7	Healthy/Normal
UT30-03	Male	4	4	3	3	3	16	72.25	53-92	71	1.25	34	Obesity
UT07-06	Male	4	4	2	3	2	15	66.71	39-91	71	-4.29	40	Obesity
UT39-05 (RIGHT)	Male	5	4	2	3	3	17	72.25	53-92	71	1.25	37	Obesity
UT19-05D	Male	5	3	2	2	2	14	59.94	29-88	71	-11.06	21.9	Healthy/Normal
UT05-04D	Male	5	2	1	3	2	13	59.94	29-88	72	-12.06	21.9	Healthy/Normal
UT43-04D	Male	4	4	3	3	2	16	72.25	53-92	72	0.25	19.1	Healthy/Normal
UT71-09D	Male	4	4	1	3	2	15	66.71	39-91	73	-6.29	20.7	Healthy/Normal
UT81-11D	Male	5	4	2	3	2	16	72.25	53-92	73	-0.75	34.7	Obesity
UT11-12D	Male	4	3	2	3	2	14	59.94	29-88	80	-20.06	21.9	Healthy/Normal
UT14-03D	Male	4	3	2	2	2	13	59.94	29-88	50	9.94	31	Obesity
UT61-04D	Male	5	3	1	2	2	13	51.41	29-81	50	1.41	36.3	Obesity
UT49-08	Male	3	3	1	3	2	12	51.41	29-81	50	1.41	22	Healthy/Normal
UT85-06D	Male	5	3	2	2	2	14	59.94	29-88	50	9.94	23.7	Healthy/Normal
UT64-05	Male	4	3	3	2	1	13	59.94	29-88	51	8.94	19.9	Healthy/Normal
UT78-05	Male	3	2	2	3	2	12	51.41	29-81	53	-1.59	19	Healthy/Normal
UT21-07	Male	4	3	3	2	1	13	59.94	29-88	54	5.94	23	Healthy/Normal
UT04-93	Male	4	4	2	3	2	15	66.71	39-91	54	12.71	24	Healthy/Normal
UT83-05	Male	4	4	2	2	2	14	59.94	29-88	54	5.94	23	Healthy/Normal
UT69-05D	Male	4	2	2	3	2	13	59.94	29-88	55	4.94	43.1	Obesity
UT95-10D	Male	4	4	2	3	2	15	66.71	39-91	55	11.71	30.4	Obesity
UT84-11D	Male	4	3	1	3	2	13	59.94	29-88	55	4.94	31.9	Obesity
UT18-07	Male	4	3	2	3	2	14	59.94	29-88	56	3.94	24	Healthy/Normal
UT06-05	Male	5	4	3	3	2	17	72.25	53-92	56	16.25	23	Healthy/Normal
UT08-04	Male	4	4	1	3	2	14	59.94	29-88	57	2.94	22	Healthy/Normal
UT67-05D	Male	4	3	2	3	2	14	59.94	29-88	58	1.94	44.2	Obesity
UT50-11D	Male	4	3	2	3	2	14	59.94	29-88	59	0.94	33.2	Obesity
UT03-05D	Male	4	4	2	3	1	14	59.94	29-88	59	0.94	31	Obesity
UT16-00	Male	4	4	1	3	2	14	59.94	29-88	61	-1.06	21	Healthy/Normal
UT37-05	Male	4	2	2	3	2	13	59.94	29-88	62	-2.06	24	Healthy/Normal
UT05-03	Male	5	4	2	3	3	17	72.25	53-92	62	10.25	21	Healthy/Normal
UT50-03D	Male	3	3	2	3	2	13	59.94	29-88	62	-2.06	38.7	Obesity
UT26-12D	Male	5	4	2	3	2	16	66.71	39-91	62	4.71	31.1	Obesity
UT51-03D	Male	4	3	2	3	3	15	66.71	39-91	63	3.71	44.3	Obesity
UT32-02D	Male	4	4	2	3	2	15	66.71	39-91	64	2.71	38.9	Obesity

Appendix 4: All males examined in this study sorted by age-at-death.

Appendix E

UTID (All Females)	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT88-16D	Female	3	2	2	3	2	12	51.41	29-81	30	21.41	23.4	Healthy/Normal
UT62-16D	Female	3	1	2	2	1	9	37.86	16-65	30	7.86	22.9	Healthy/Normal
UT40-08D	Female	3	2	2	2	1	10	37.86	16-65	33	4.86	20.6	Healthy/Normal
UT88-10D	Female	2	2	2	2	1	9	37.86	16-65	39	-1.14	19.1	Healthy/Normal
UT36-18D	Female	3	2	1	2	1	9	37.86	16-65	42	-4.14	20.2	Healthy/Normal
UT69-06D	Female	3	2	2	2	1	10	37.86	16-65	45	-7.14	23.3	Healthy/Normal
UT113-10D	Female	4	2	2	2	2	12	51.41	29-81	45	6.41	24.3	Healthy/Normal
UT93-17D	Female	3	3	2	2	1	11	51.41	29-81	46	5.41	24	Healthy/Normal
UT11-11D	Female	3	2	2	1	2	10	37.86	16-65	46	-8.14	23.6	Healthy/Normal
UT92-05D	Female	2	3	1	2	1	9	37.86	16-65	47	-9.14	24.4	Healthy/Normal
UT79-18D	Female	3	3	3	2	3	14	59.94	29-88	49	10.94	21.3	Healthy/Normal
UT35-07	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	22	Healthy/Normal
UT09-00	Female	4	2	3	2	1	12	51.41	29-81	43	8.41	23	Healthy/Normal
UT57-09D	Female	4	3	2	2	2	13	59.94	29-88	34	25.94	39.2	Obesity
UT32-06D	Female	4	2	2	2	1	11	51.41	29-81	39	12.41	51.5	Obesity
UT60-12D	Female	3	2	2	2	1	10	37.86	16-65	40	-2.14	32.3	Obesity
UT49-09D	Female	4	3	1	2	2	12	51.41	29-81	42	9.41	41.6	Obesity
UT74-06D	Female	4	2	1	3	1	11	51.41	29-81	42	9.41	35.5	Obesity
UT51-07D	Female	3	3	2	3	2	13	59.94	29-88	44	15.94	37.8	Obesity
UT82-13D	Female	3	2	1	2	2	10	37.86	16-65	45	-7.14	51.4	Obesity
UT85-11D	Female	3	2	2	2	2	11	51.41	29-81	46	5.41	44.9	Obesity
UT62-11D	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	34	Obesity
UT81-08D	Female	4	2	2	3	1	12	51.41	29-81	46	5.41	30	Obesity
UT87-10D	Female	4	2	1	2	2	11	51.41	29-81	46	5.41	33.6	Obesity
UT128-09D	Female	4	3	1	2	3	12	59.94	29-88	48	11.94	35.2	Obesity
UT08-11D	Female	3	3	1	3	2	12	51.41	29-81	50	1.41	21.3	Healthy/Normal
UT64-10D	Female	4	3	2	2	2	13	59.94	29-88	50	9.94	20.6	Healthy/Normal
UT58-06D	Female	3	2	2	3	1	11	51.41	29-81	51	0.41	22.5	Healthy/Normal
UT33-03D	Female	4	2	2	2	2	12	51.41	29-81	51	0.41	20	Healthy/Normal
UT107-08D	Female	3	2	1	2	1	9	37.86	16-65	52	-14.14	18.9	Healthy/Normal
UT32-13D	Female	3	3	2	2	2	12	51.41	29-81	53	-1.79	24.3	Healthy/Normal
UT11-04D	Female	4	3	1	2	1	11	51.41	29-81	54	-2.79	23	Healthy/Normal
UT48-15D	Female	4	3	1	3	1	11	51.41	29-81	55	-3.79	20.9	Healthy/Normal
UT42-06D	Female	3	2	1	2	2	10	37.86	16-65	56	-18.14	23.6	Healthy/Normal
UT08-07D	Female	4	3	2	3	2	14	59.94	29-88	57	2.94	24.7	Healthy/Normal
UT10-17D	Female	4	2	1	2	2	11	51.41	29-81	58	-6.59	22.6	Healthy/Normal
UT29-03D	Female	3	2	1	3	1	10	37.86	16-65	59	-21.14	18.5	Healthy/Normal
UT10-07D	Female	4	4	2	2	1	13	59.94	29-88	50	9.94	35	Obesity
UT39-03D	Female	3	2	1	2	3	11	51.41	29-81	52	-0.59	32.9	Obesity
UT31-13D	Female	4	3	2	2	2	13	59.94	29-81	52	7.94	30.1	Obesity
UT62-09D	Female	3	3	2	2	2	12	51.41	29-81	52	-0.59	35.5	Obesity
UT54-05D	Female	3	2	2	2	2	11	51.41	29-81	54	-2.59	30.8	Obesity
UT61-05D	Female	4	1	2	1	2	10	37.86	16-65	55	-17.14	31.1	Obesity
UT72-08D	Female	4	2	1	2	2	11	51.41	29-81	55	-3.59	42	Obesity
UT87-11D	Female	4	3	1	2	2	12	51.41	29-81	57	2.94	30.9	Obesity
UT100-06D	Female	4	3	2	3	2	15	66.71	39-91	57	9.71	37.1	Obesity
UT17-05D	Female	4	3	2	2	2	13	59.94	29-88	58	1.94	39.8	Obesity
UT15-06D (right)	Female	5	2	2	2	3	14	59.94	29-88	58	1.94	40.3	Obesity
UT32-17D	Female	4	3	1	2	2	13	59.94	29-88	61	-1.06	34.9	Obesity
UT70-13D	Female	3	3	3	2	2	13	59.94	29-88	62	-2.06	43.2	Obesity
UT44-10D	Female	4	3	2	2	2	13	59.94	29-88	62	-2.06	40.2	Obesity
UT14-19D	Female	4	3	1	3	2	13	59.94	29-88	63	-3.06	30.3	Obesity
UT45-11D	Female	3	2	1	2	3	11	51.41	29-81	65	-13.59	23.6	Healthy/Normal
UT105-07D	Female	3	3	2	3	3	14	59.94	29-88	68	-8.06	23.4	Healthy/Normal
UT16-12D	Female	4	2	1	2	2	11	51.41	29-81	68	-16.59	21.6	Healthy/Normal
UT92-16D	Female	3	3	2	3	2	13	59.94	29-88	68	-8.06	22.8	Healthy/Normal
UT38-17D	Female	4	3	2	3	1	13	59.94	29-88	69	-9.06	18.6	Healthy/Normal
UT21-16D	Female	2	3	1	3	1	10	37.86	16-65	70	-22.14	18.9	Healthy/Normal
UT95-16D	Female	5	3	2	2	1	13	59.94	29-88	70	-10.06	23.9	Healthy/Normal
UT104-17D	Female	4	3	2	2	2	13	51.41	29-81	71	-19.59	22.2	Healthy/Normal
UT109-10D	Female	4	2	2	3	1	12	51.41	29-81	73	-21.59	22.1	Healthy/Normal
UT20-17D	Female	5	3	2	3	2	15	66.71	39-91	74	-7.29	21.9	Healthy/Normal
UT02-05D	Female	4	2	3	2	3	14	59.94	29-88	76	-16.06	21	Healthy/Normal
UT82-17D	Female	5	4	2	2	1	14	59.94	29-88	77	-17.06	21	Healthy/Normal
UT15-09D	Female	4	3	3	3	2	15	66.71	39-91	77	-9.29	23	Healthy/Normal
UT69-15D	Female	5	3	2	3	2	15	66.71	39-91	66	0.71	30.1	Obesity
UT14-18D	Female	4	4	2	3	2	15	66.71	39-91	67	-0.29	39.2	Obesity
UT07-07	Female	4	4	3	2	2	15	66.71	39-91	67	-0.29	31	Obesity
UT20-06	Female	4	4	3	2	2	15	66.71	39-91	71	-4.29	38	Obesity
UT19-00	Female	4	4	2	3	3	16	66.71	39-91	72	-5.29	36	Obesity
UT62-04D	Female	3	3	1	3	2	12	51.41	29-81	73	-21.59	35.9	Obesity
UT32-04	Female	3	4	3	3	2	14	59.94	29-88	73	-12.06	32	Obesity
UT45-03	Female	4	3	3	3	2	15	66.71	39-91	73	-6.29	34	Obesity
UT96-06	Female	4	3	3	3	2	14	59.94	29-88	73	-12.06	35	Obesity
UT13-05	Female	3	3	3	3	2	13	51.41	29-81	74	-22.59	40	Obesity
UT26-11D	Female	5	4	3	3	2	17	72.25	53-92	76	-3.75	33.8	Obesity
UT06-18D	Female	4	4	3	3	2	15	66.71	39-91	77	-10.29	30.9	Obesity

Appendix 5: All females examined in this studied sorted by healthy and obese body mass between the 30-49, 50-64, and 65-80 age groups.

Appendix F

UTID (All Females by Age)	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT88-16D	Female	3	2	2	3	2	12	51.41	29-81	30	21.41	23.4	Healthy/Normal
UT62-16D	Female	3	1	2	2	1	9	37.86	16-65	30	7.86	22.9	Healthy/Normal
UT40-08D	Female	3	2	2	2	1	10	37.86	16-65	33	4.86	20.6	Healthy/Normal
UT57-09D	Female	4	3	2	2	2	13	59.94	29-88	34	25.94	39.2	Obesity
UT32-06D	Female	4	2	2	2	1	11	51.41	29-81	39	12.41	51.5	Obesity
UT88-10D	Female	2	2	2	2	1	9	37.86	16-65	39	-1.14	19.1	Healthy/Normal
UT60-12D	Female	3	2	2	2	1	10	37.86	16-65	40	-2.14	32.3	Obesity
UT49-09D	Female	4	3	1	2	2	12	51.41	29-81	42	9.41	41.6	Obesity
UT74-06D	Female	4	2	1	3	1	11	51.41	29-81	42	9.41	35.5	Obesity
UT36-18D	Female	3	2	1	2	1	9	37.86	16-65	42	-4.14	20.2	Healthy/Normal
UT09-00	Female	4	2	3	2	1	12	51.41	29-81	43	8.41	23	Healthy/Normal
UT51-07D	Female	3	3	2	3	2	13	59.94	29-88	44	15.94	37.8	Obesity
UT82-13D	Female	3	2	1	2	2	10	37.86	16-65	45	-7.14	51.4	Obesity
UT69-06D	Female	3	2	2	2	1	10	37.86	16-65	45	-7.14	23.3	Healthy/Normal
UT113-10D	Female	4	2	2	2	2	12	51.41	29-81	45	6.41	24.3	Healthy/Normal
UT85-11D	Female	3	2	2	2	2	11	51.41	29-81	46	5.41	44.9	Obesity
UT62-11D	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	34	Obesity
UT81-08D	Female	4	2	2	3	1	12	51.41	29-81	46	5.41	30	Obesity
UT87-10D	Female	4	2	1	2	2	11	51.41	29-81	46	5.41	33.6	Obesity
UT35-07	Female	3	3	1	3	1	11	51.41	29-81	46	5.41	22	Healthy/Normal
UT93-17D	Female	3	3	2	2	1	11	51.41	29-81	46	5.41	24	Healthy/Normal
UT11-11D	Female	3	2	2	1	2	10	37.86	16-65	46	-8.14	23.6	Healthy/Normal
UT92-05D	Female	2	3	1	2	1	9	37.86	16-65	47	-9.14	24.4	Healthy/Normal
UT128-09D	Female	4	3	1	2	3	12	59.94	29-88	48	11.94	35.2	Obesity
UT79-18D	Female	3	3	3	2	3	14	59.94	29-88	49	10.94	21.3	Healthy/Normal
UT08-11D	Female	3	3	1	3	2	12	51.41	29-81	50	1.41	21.3	Healthy/Normal
UT64-10D	Female	4	3	2	2	2	13	59.94	29-88	50	9.94	20.6	Healthy/Normal
UT10-07D	Female	4	4	2	2	1	13	59.94	29-88	50	9.94	35	Obesity
UT58-06D	Female	3	2	2	3	1	11	51.41	29-81	51	0.41	22.5	Healthy/Normal
UT33-03D	Female	4	2	2	2	2	12	51.41	29-81	51	0.41	20	Healthy/Normal
UT39-03D	Female	3	2	1	2	3	11	51.41	29-81	52	-0.59	32.9	Obesity
UT31-13D	Female	4	3	2	2	2	13	59.94	29-81	52	7.94	30.1	Obesity
UT62-09D	Female	3	3	2	2	2	12	51.41	29-81	52	-0.59	35.5	Obesity
UT107-08D	Female	3	2	1	2	1	9	37.86	16-65	52	-14.14	18.9	Healthy/Normal
UT32-13D	Female	3	3	2	2	2	12	51.41	29-81	53	-1.59	24.3	Healthy/Normal
UT11-04D	Female	4	3	1	2	1	11	51.41	29-81	54	-2.59	23	Healthy/Normal
UT54-05D	Female	3	2	2	2	2	11	51.41	29-81	54	-2.59	30.8	Obesity
UT61-05D	Female	4	1	2	1	2	10	37.86	16-65	55	-17.14	31.1	Obesity
UT72-08D	Female	4	2	1	2	2	11	51.41	29-81	55	-3.59	42	Obesity
UT48-15D	Female	4	3	1	3	1	11	51.41	29-81	55	-3.59	20.9	Healthy/Normal
UT42-06D	Female	3	2	1	2	2	10	37.86	16-65	56	-18.14	23.6	Healthy/Normal
UT87-11D	Female	4	3	1	2	2	12	51.41	29-81	57	5.59	30.9	Obesity
UT100-06D	Female	4	3	2	3	2	15	66.71	39-91	57	9.71	37.1	Obesity
UT08-07D	Female	4	3	2	3	2	14	59.94	29-88	57	2.94	24.7	Healthy/Normal
UT17-05D	Female	4	3	2	2	2	13	59.94	29-88	58	1.94	39.8	Obesity
UT15-06D (right)	Female	5	2	2	2	3	14	59.94	29-88	58	1.94	40.3	Obesity
UT10-17D	Female	4	2	1	2	2	11	51.41	29-81	58	-6.59	22.6	Healthy/Normal
UT29-03D	Female	3	2	1	3	1	10	37.86	16-65	59	-21.14	18.5	Healthy/Normal
UT32-17D	Female	4	3	1	2	2	13	59.94	29-88	61	-1.06	34.9	Obesity
UT70-13D	Female	3	3	3	2	2	13	59.94	29-88	62	-2.06	43.2	Obesity
UT44-10D	Female	4	3	2	2	2	13	59.94	29-88	62	-2.06	40.2	Obesity
UT14-19D	Female	4	3	1	3	2	13	59.94	29-88	63	-3.06	30.3	Obesity
UT45-11D	Female	3	2	1	2	3	11	51.41	29-81	65	-13.59	23.6	Healthy/Normal
UT69-15D	Female	5	3	2	3	2	15	66.71	39-91	66	0.71	30.1	Obesity
UT14-18D	Female	4	4	2	3	2	15	66.71	39-91	67	-0.29	39.2	Obesity
UT07-07	Female	4	4	3	2	2	15	66.71	39-91	67	-0.29	31	Obesity
UT105-07D	Female	3	3	2	3	3	14	59.94	29-88	68	-8.06	23.4	Healthy/Normal
UT16-12D	Female	4	2	1	2	2	11	51.41	29-81	68	-16.59	21.6	Healthy/Normal
UT92-16D	Female	3	3	2	3	2	13	59.94	29-88	68	-8.06	22.8	Healthy/Normal
UT38-17D	Female	4	3	2	3	1	13	59.94	29-88	69	-9.06	18.6	Healthy/Normal
UT21-16D	Female	2	3	1	3	1	10	37.86	16-65	70	-32.14	18.9	Healthy/Normal
UT95-16D	Female	5	3	2	2	1	13	59.94	29-88	70	-10.06	23.9	Healthy/Normal
UT104-17D	Female	4	3	2	2	2	13	51.41	29-81	71	-19.59	22.2	Healthy/Normal
UT20-06	Female	4	4	3	2	2	15	66.71	39-91	71	-4.29	38	Obesity
UT19-00	Female	4	4	2	3	3	16	66.71	39-91	72	-5.29	36	Obesity
UT109-10D	Female	4	2	2	3	1	12	51.41	29-81	73	-21.59	22.1	Healthy/Normal
UT62-04D	Female	3	3	1	3	2	12	51.41	29-81	73	-21.59	35.9	Obesity
UT32-04	Female	3	4	3	3	2	14	59.94	29-88	73	-12.06	32	Obesity
UT45-03	Female	4	3	3	3	2	15	66.71	39-91	73	-6.29	34	Obesity
UT96-06	Female	4	3	3	3	2	14	59.94	29-88	73	-12.06	35	Obesity
UT20-17D	Female	5	3	2	3	2	15	66.71	39-91	74	-7.29	21.9	Healthy/Normal
UT13-05	Female	3	3	3	3	2	13	51.41	29-81	74	-14.06	40	Obesity
UT02-05D	Female	4	2	3	2	3	14	59.94	29-88	76	-16.06	21	Healthy/Normal
UT26-11D	Female	5	4	3	3	2	17	72.25	53-92	76	-3.75	33.8	Obesity
UT06-18D	Female	4	4	3	3	2	15	66.71	39-91	77	-10.29	30.9	Obesity
UT82-17D	Female	5	4	2	2	1	14	59.94	29-88	77	-17.06	21	Healthy/Normal
UT15-09D	Female	4	3	3	3	2	15	66.71	39-91	77	-9.29	23	Healthy/Normal

Appendix 6: All females examined in this study sorted by age-at-death.

Appendix G

UTID	M/F	T.O	S.T.	Macro	Micro	A.C.	Total	Mean Age	Age Range	Actual Age	Inaccuracy	BMI Level	Category
UT06-05	Male	5	4	3	3	2	17	72.25	53-92	56	16.25	23	Healthy/Normal
UT04-10D	Male	3	3	2	2	1	11	51.41	29-81	35	16.41	23.6	Healthy/Normal
UT36-05	Male	2	3	3	2	2	13	59.94	29-88	41	18.94	22	Healthy/Normal
UT88-16D	Female	3	2	2	3	2	12	51.41	29-81	30	21.41	23.4	Healthy/Normal
UT02-05D	Female	4	2	3	2	3	14	59.94	29-88	76	-16.06	21	Healthy/Normal
UT16-12D	Female	4	2	1	2	2	11	51.41	29-81	68	-16.59	21.6	Healthy/Normal
UT82-17D	Female	5	4	2	2	1	14	59.94	29-88	77	-17.06	21	Healthy/Normal
UT63-17D	Male	5	2	1	2	2	11	51.41	29-81	69	-17.59	23	Healthy/Normal
UT42-06D	Female	3	2	1	2	2	10	37.86	16-65	56	-18.14	23.6	Healthy/Normal
UT104-17D	Female	4	3	2	2	2	13	51.41	29-81	71	-19.59	22.2	Healthy/Normal
UT11-12D	Male	4	3	2	3	2	14	59.94	29-88	80	-20.06	21.9	Healthy/Normal
UT29-03D	Female	3	2	1	3	1	10	37.86	16-65	59	-21.14	18.5	Healthy/Normal
UT109-10D	Female	4	2	2	3	1	12	51.41	29-81	73	-21.59	22.1	Healthy/Normal
UT21-16D	Female	2	3	1	3	1	10	37.86	16-65	70	-32.14	18.9	Healthy/Normal
UT51-07D	Female	3	3	2	3	2	13	59.94	29-88	44	15.94	37.8	Obesity
UT38-10D	Male	3	3	3	2	1	12	51.41	29-81	35	16.41	38	Obesity
UT37-03D	Male	3	3	3	2	3	14	59.94	29-88	43	16.94	31.9	Obesity
UT89-07	Male	4	3	2	2	3	14	59.94	29-88	43	16.94	32	Obesity
UT25-04	Male	4	4	2	2	2	14	59.94	29-88	40	19.94	34	Obesity
UT55-17D	Male	3	3	2	2	2	12	51.41	29-81	31	20.41	36	Obesity
UT57-09D	Female	4	3	2	2	2	13	59.94	29-88	34	25.94	39.2	Obesity
UT24-09D	Male	5	3	2	2	2	14	59.94	29-88	33	26.94	40.7	Obesity
UT61-05D	Female	4	1	2	1	2	10	37.86	16-65	55	-17.14	31.1	Obesity
UT62-04D	Female	3	3	1	3	2	12	51.41	29-81	73	-21.59	35.9	Obesity

Appendix 7: Individuals separated by inaccuracy levels above positive 15.00 and below negative 15.00. Individuals below and above these values were considered to be outliers.

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