THE IMPACT OF FAT MASS ON DECOMPOSITION RATE AND POSTMORTEM INTERVAL ESTIMATION

by

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DEDICATION

This work is dedicated to my mother, Dr. Lee Miller. Thank you for everything.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
PMI	Postmortem Interval
TBS	Total Body Score
BMI	Body Mass Index
KG	Kilograms
LBS	Pounds
CDC	Centers for Disease Control
WHO	World Health Organization
DXA	Dual-energy X-Ray Absorptiometry
ADD	Accumulated Degree Days
FARF	Forensic Anthropology Research Facility
FACTS	Forensic Anthropology Center at Texas State
OZ	Ounces

ABSTRACT

It is unclear whether body mass, or fat mass, affects the rate of human decomposition. This study is aimed at further investigation of the true effect of fat mass on the rate of early to advanced human decomposition in order to provide more accurate postmortem interval (PMI) estimations. The decomposition processes of 16 females and 9 males in different Body Mass Index (BMI) categories were monitored. The Accumulated Degree Days (ADD) needed to reach skeletonization of the trunk were compared between the BMI categories and among obese and non-obese individuals. Additional subcutaneous fat measurements from nine of the donors were collected to determine if BMI is an accurate indicator of fat mass and if fat deposit locations differ between men and women. Blowfly larvae feeding preferences were also examined. The results indicate that there is not a significant difference in the rate of early to advanced decomposition between individuals in the different BMI categories but trends towards significance when the categories are collapsed into obese and non-obese individuals. Additionally, the results suggest that there may be a difference in decomposition rate during advanced and later stages of decomposition. It was found that BMI is not an accurate predictor of fat mass and that fat deposit locations do not differ between obese individuals. Lastly, it appears that maggots consume muscle tissue and not fat or skin. The results of this study suggest the need for further analyses into the effect of fat mass throughout the entire decomposition process.

I. INTRODUCTION

This research project examined the effect of fat mass on decomposition rate, in order to expand research on some of the factors that impact postmortem interval estimation (PMI). PMI, or time since death, is important in forensic contexts because it allows investigators to obtain a potential window of when the individual died, which assists in both narrowing down possible individuals for faster identification and identifying possible perpetrators. However, despite much research aimed at quantifying the PMI (e.g., Byard, 2020; Cameron & Oxenham, 2020; Ferreira & Cunha, 2013; Love & Marks, 2003; Mann et al., 1990; Megyesi et al., 2005; Schotsmans et al., 2020; Wallman & Archer, 2020) there is yet to be a standard and precise method of calculating PMI based on decomposition rate (Ferreira & Cunha, 2013).

This lack of standardization is due to the multiple intrinsic and extrinsic factors that affect decomposition rate and thus, PMI estimation. To address the impact of fat mass on decomposition rate and PMI, the Total Body Score (TBS) and subcutaneous fat of individuals in different Body Mass Index (BMI) categories were compared. Determining if fat mass impacts PMI is important to the broad scope of anthropology because there is substantial human variation in body fat. Additionally, there is an increasing need for determining the effect of fat mass on PMI as the prevalence of obesity continues trending upward across the globe (Hales et al., 2020; World Health Organization [WHO], 2020).

Background

Postmortem Interval and Decomposition Rate

Decomposition generally occurs in five major stages: fresh, early decomposition, advanced decomposition, skeletonization and finally, skeletal decomposition (Galloway, 1997). Within these categories, there are secondary stages that indicate the overall condition of the remains, but not necessarily the sequence of events (Galloway, 1997). Some of these secondary stages include various types of discoloration, skin slippage, marbling, purging, caving of the abdominal cavity and sagging flesh, and mummification (Galloway, 1997). According to Parks (2011), the decomposition sequence in Central Texas closely follows the sequence laid out by Galloway based on decomposition analysis of remains in arid regions, allowing the same decomposition stages to be utilized for this research. The dry air and intense sunlight in Central Texas cause the remains to mummify, with dried tissue remaining for long periods of time.

The decomposition sequence and rate are affected by many different factors that are both extrinsic and intrinsic. The main extrinsic factors that affect the rate of decomposition include temperature, humidity, rainfall, soil pH, insect and carnivore activity, and location of the remains (Byard, 2020; Campobasso et al., 2001; Mann et al., 1990; Wallman & Archer, 2020). Temperature appears to have the greatest impact on the rate of decomposition, as the process slows greatly or may even stagnate as temperatures approach freezing (Byard, 2020; Mann et al., 1990). Fly eggs and maggots die in cold temperatures and decreased insect activity will decrease decomposition rate, as most soft-tissue decomposition is the result of insect feeding (Campobasso et al., 2001; Mann et al., 1990; Wallman & Archer, 2020).

Humidity also appears to be a key factor in decomposition rate, as increased humidity leads to increased insect activity, while decreased humidity often results in desiccated human remains (Galloway et al., 1989; Mann et al., 1990). With this said, the decomposition rate of human remains will differ depending on the climate. For example, Galloway (1997) found that in the dry Arizona-Sonora desert, the combination of high temperatures and low humidity increased the rate of early decomposition and resulted in mummification of the remains, which differs from decomposition in other regions. As noted above, Parks (2011) found that the decomposition rate in Central Texas closely aligns with other decomposition studies conducted in the Southwestern United States.

The placement of the remains, either on the surface or buried also has an impact on the rate of decomposition (Ferreira & Cunha, 2013; Mann et al., 1990). Bodies placed on the surface will decompose faster than buried remains, and the depth of the buried remains also plays an important role (Campobasso et al., 2001; Mann et al., 1990). Buried remains will have a slower rate of decomposition due to decreased oxygen, decreased insect and animal activity, and decreased exposure to the important environmental factors like solar radiation (Ferreira & Cunha, 2013; Wallman & Archer, 2020).

The temperature of buried remains is generally more consistent over time and is often lower, which decreases the rate of decomposition (Campobasso et al., 2001; Ferreira & Cunha, 2013). Ferreira and Cunha (2013) conducted a study on the decomposition rate of buried remains where the postmortem interval and the depositional environment of the remains were similar, and found a wide range of decomposition stages, further complicating PMI estimation based on decomposition rate. Because of the significant impact temperature, humidity, and placement of the remains have on decomposition rate, these factors must be accounted for when estimating postmortem interval and decomposition studies in various climates must be conducted.

As for intrinsic factors, it is generally assumed that body mass, and thus, fat mass, impact the rate of human decomposition (Byard, 2020; Campobasso et al., 2001; Mann et al., 1990). Logically, this makes sense as larger individuals would have more soft tissue to decompose. However, there does not appear to be consensus in the research literature about the effect of body mass and fat mass on decomposition rate. Furthermore, the majority of decomposition studies examining body mass do not differentiate between fat mass and body mass, as most studies are using animal models instead of human cadavers.

For example, Matuszewski et al. (2016) reported larger, longer lasting, and more varied insect assemblages were found on larger animal carcasses. As previously discussed, insects play a crucial role in the decomposition rate of soft tissues and insect assemblages are often used to estimate the postmortem interval. Thus, if there is a difference in insect succession and habitation between large and small carcasses, the PMI estimation for different body masses will likely differ as well (Matuszewski et al., 2016).

Additionally, Sutherland et al. (2013) conducted a study to examine the effect of body mass on decomposition rate using pig carcasses ranging from 3 kg to 90 kg (6.61 lbs to 198.42 lbs). This study reported that there was little difference between body masses in the early stages of decomposition; however, during later decomposition stages the smaller carcasses decomposed at a much faster rate, and the progression of the decomposition stages differed between small and large carcasses (Sutherland et al., 2013). Overall, the conclusions of this study were that body mass does have an effect on decomposition rate and postmortem interval, so PMI estimations based on larger carcasses should not be used to estimate PMI for smaller carcasses and vice versa (Sutherland et al., 2013). Ferreira and Cunha (2013) also note that the human remains in their study with very low body mass were found to have skeletonized more rapidly, while the individuals with higher body mass had adipocere formation, which decreases decomposition rate.

The Roberts et al. (2017) study, one of the few that has been conducted on human remains, examined the effect of body mass on decomposition rate in 12 human cadavers, ranging in body mass from 73 kg to 159 kg (160.94 lbs to 350.53 lbs). They found body mass did not affect PMI estimation and could only account for up to 24% of the difference in decomposition rate between individuals with different body masses (Roberts et al., 2017). However, this study only looked at individuals of different body masses instead of individuals with different amounts of fat mass and was conducted in a specific climate (Southern Illinois) with a relatively small sample.

The review of decomposition literature reveals that there are many different factors affecting decomposition rate, with very few studies addressing the impact of fat mass. This lack of information is likely because decomposition studies are difficult to conduct, and many were retrospective studies or analyses done on forensic cases where fat mass was not taken into consideration. Additionally, the scarcity of information on fat mass within decomposition analyses indicates that individuals with high and low fat mass are marginalized populations in the decomposition literature. Furthermore, the few recent studies that have attempted to examine body mass and decomposition have not used human models (i.e., Matuszewski et al., 2016; Sutherland et al., 2013), or have not examined fat mass specifically (Roberts et al., 2017).

This current study uses a wide range of individuals with differing amounts of fat mass to increase the representation of previously excluded body types and allows for a comparative analysis that will better indicate the true effect fat mass has on decomposition rate and PMI estimation.

Obesity and Body Mass Index

As discussed in the previous section, most PMI studies have not addressed fat mass and the studies that have were conducted on non-human models or have not examined the role fat mass plays in decomposition rate. This lack of research needs to be addressed because if the linkage between body fat and PMI is unknown, forensic anthropologists may inaccurately predict PMI, which hinders faster identification within forensic contexts. Moreover, as obesity becomes more prevalent in the United States and across the globe, the methods for estimating postmortem interval need to be adjusted to accommodate for an increased number of individuals with high fat mass (Hales et al., 2020).

Obesity can be defined as excess fat (Flegal et al., 2009; Nuttall, 2015; Romero-Corral et al., 2008). According to the Centers for Disease Control (CDC), the prevalence of obesity among adults in the United States, adjusted for age, was 42.4% (Hales et al., 2020). Worldwide, the prevalence of obesity increased from 28.8% in 1980 to 36.9% in 2013, which is an 8.1% increase over 33 years (Ng et al., 2014). The CDC defines obesity as "…a BMI greater than or equal to 30" (Hales et al., 2020, p. 5) and severe obesity as "…a BMI greater than or equal to 40" (Hales et al., 2020, p. 5). BMI stands for

Body Mass Index and is found by dividing an individual's weight in kilograms (kg) by their height in centimeters (cm) squared. The formula is: BMI = m/h^2, where *m* stands for mass in kg and *h* stands for height in cm.

The World Health Organization (WHO) BMI categories were utilized in this research, as they provide more specific categories (6) than other BMI scales that only use the three broad categories of underweight, normal, and obese (WHO, 2020, p. 9). These categories allow for a more nuanced understanding of how BMI affects PMI (Table 1).

Table 1. World Health Organization Body Mass Index Categories. The six BMI classes outlined by the WHO are in the left column and the BMI scores that correlate with these categories are in the right.

BMI Class	BMI Range
Underweight	BMI < 18.5
Normal	BMI 18.50 – 24.99
Pre-obese	BMI 25.00 – 29.99
Obese Class I	BMI 30.00 – 34.99
Obese Class II	BMI 35.00 – 39.99
Obese Class III	BMI > 40.00

There are issues with using BMI categories to define obesity as BMI measures total body mass, without differentiating between an individual's lean body mass and fat mass (Flegal et al., 2009; Henneberg & Ulijaszek, 2010; Lee et al., 2017; Nuttall, 2015; Romero-Corral et al., 2008). This failure to distinguish between lean body mass and fat mass presents issues for individuals like athletes, who have larger amounts of lean muscle mass and may be categorized as obese based on BMI measurements. BMI measurements have also been found to be generally less accurate in men than women for the same reason. The most accurate way to measure an individual's body fat is Dual-energy X-Ray absorptiometry (DXA), but this requires specialized and expensive technology and is difficult to use on large sample sizes (Flegal et al., 2009; Lee et al., 2017). Because of the inaccessibility of DXA, there have been many studies that use other anthropometric measurements, which are easy to conduct in the field and require few instruments, in addition to BMI, to predict fat mass more accurately (Flegal et al., 2009; Henneberg & Ulijaszek, 2010; Lee et al., 2017; Wang et al., 2003).

Because BMI is still used to define obesity today, and it is still relatively well associated with amount of body fat an individual has, BMI was used to determine broad categories in this study, with the addition of several anthropometric measurements shown to predict fat mass more accurately. These additional measurements include waist-circumference, thigh circumference, and measures of subcutaneous fat (Flegal et al., 2009; Henneberg & Ulijaszek, 2010; Lee et al., 2017; Wang et al., 2003). Measures of subcutaneous fat allow for the identification of specific fat amount thresholds that may impact the rate or sequence of decomposition (i.e., at what amount of subcutaneous fat does the decomposition rate differ). Skinfold thickness will not be measured as it cannot always be obtained (in the case of large individuals) and it is unknown if skinfold thickness measurements are as accurate in estimating fat mass in deceased individuals (Wang et al., 2000). By including the additional measurements described above, the accuracy of BMI categories is increased and a more detailed perspective on the relationship between fat and decomposition rate is provided.

Often, human decomposition studies are difficult to conduct due to a variety of factors including obtaining study subjects, proper facilities for placement and research, and negative public opinion for outdoor decomposition research laboratories in general (Mann et al., 1990). The lack of information on the impact of fat mass on postmortem interval indicates that individuals with high fat mass are underrepresented in decomposition studies. This is an issue because if fat mass impacts postmortem interval, previous studies and descriptions of decomposition rates for individuals with 'normal' levels of fat mass would not apply as well to individuals with high fat mass, who will be seen more in forensic contexts as the prevalence of obesity continues to rise in the United States.

Human Gut Microbiomes and Dipteran Diet

The goals of this research project were not only to determine if fat mass impacts decomposition, but if so, why, and what are the possible causes. Two different factors may affect the rate of decomposition between individuals with high and low fat mass: the microbes in the human gut, and insect activity.

Decomposition begins almost immediately after an individual dies. The cells lack oxygen, which increases the level of carbon monoxide in the body and decreases the pH levels, poisoning the cells and leading to a process called autolysis (Love & Marks, 2003). Autolysis is the destruction of cells by cellular enzymes, causing the cells to eventually rupture and release fluids that are filled with nutrients (Love & Marks, 2003). The process of putrefaction, or the breakdown of soft tissue by bacteria within the body, often coincides with autolysis (Byard, 2020; Love & Marks, 2003). The proliferation of anaerobic bacteria responsible for putrefaction begins in the gut and then moves through the rest of the body (Byard, 2020).

However, it has been found that the microbial ecology of the human gut differs between lean and obese individuals (Castaner, 2018; Ley et al., 2005; Ley et al., 2006). The most prolific bacteria in the human gut are members of the phyla Bacteriodetes and Firmicutes, which account for about 90% of the total bacterial species (Castaner, 2018). Obese individuals have more Firmicutes and fewer Bacteriodetes, while the opposite is true for lean individuals (Castaner, 2018; Ley et al., 2005; Ley et al., 2006). Because bacteria within the gut are the driving force behind putrefaction, the difference in gut microbial ecology between obese and lean individuals may affect the rate of early decomposition.

Additionally, necrophagous arthropods, or insects that consume decaying tissue, also play an important in role in decomposition (Campobasso et al., 2001; Turner, 2005; Wallman & Archer, 2020). Certain species within the order Diptera (flies), like Calliphoridae (blowflies), are commonly associated with decomposition as their larvae (maggots) rely on remains as a food source and can arrive quickly after death occurs (Turner, 2005; Wallman & Archer, 2020). A female blowfly can lay up to 300 eggs in one landing and the larvae will hatch after 1-2 days (Turner, 2005). These larvae will first feed on serous fluids and then on the soft tissues of the body (Turner, 2005). Maggot feeding and activity can remove biomass and liquify tissues and are thus closely linked to the rate of decomposition (Turner, 2005; Wallman & Archer, 2020).

Although this close association between tissue consumption by maggots and decomposition is well known and has been closely studied, it is unclear in the literature which types of soft tissues maggots consume, either first as a preference or in general. In discussions, an entomologist indicated that blowfly larvae likely do not consume subcutaneous fat (A. Brundage, personal communication, June 20th, 2022). Because of the close association between maggot activity and decomposition rate, understanding how maggots respond to fat is important to consider. In order to determine if maggots consume fat as readily as other tissues like muscle, or at all, four tissue samples were obtained and monitored for maggot and other insect activity during the data collection process.

Total Body Score and Accumulated Degree Days

To determine the effect of fat mass and BMI on PMI, the Total Body Score (TBS) and subcutaneous fat measurements of the individuals in this study were compared. TBS is the summation of different decomposition scores given for different sections of the body: the head and neck, the trunk, and limbs (Megyesi et al., 2005). The different parts of the body are scored separately and then added together to produce a summed score because decomposition for each of these three sections occurs differently (Megyesi et al., 2005). For example, limbs do not go through a purging or bloating phase, unlike other body sections, so the scoring must reflect these differences in decomposition (Megyesi et al., 2005). The categories of decomposition for the head and neck, trunk, and limbs are fresh, early decomposition, advanced decomposition, and skeletonization (Megyesi et al., 2005). For each of the body regions, the scoring distribution is different, accounting for the differences in decomposition (Megyesi et al., 2005). TBS ranges from 1 point to 10, 12, or 13 points, depending on the area of the body that is being scored (Megyesi et al., 2005).

Because of the significant impact of temperature and humidity on decomposition rate, Accumulated Degree Days (ADD), which "represent heat energy units available to propel a biological process such as bacterial or fly larvae growth" (Megyesi et al., 2005, p. 4) are used as a measure of time. The Megyesi et al. (2005) study found that ADD can account for up to 80% of the variation seen in the rate of decomposition, which indicates that ADD must be used in conjunction with TBS to determine the decomposition rate of individuals with varying fat masses (Megyesi et al., 2005). The weather station at the Forensic Anthropology Research Facility (FARF), where data collection took place, was used to obtain the most accurate temperature data to calculate ADD.

Like many of the other decomposition studies, the seminal Megyesi et al. (2005) study was a retrospective analysis done on different forensic cases. As noted above, many studies concerning decomposition rate and PMI fail to address fat mass, and this holds true for the Megyesi et al. (2005) study as well. As such, this research project examines how TBS sequence and decomposition rate based on TBS may differ between body mass classes and fat mass amounts.

Goals and Research Questions

Understanding the impact of fat mass on postmortem interval estimation is important to time since death estimation both in forensic anthropology and in other medico-legal contexts. As outlined above, the lack of consensus on this topic illustrates the need for this type of study to be conducted. Furthermore, the general trend in increasing fat mass in humans is also an impetus for working towards a more comprehensive answer on the impact of fat mass on decomposition rate. The overall goals of this study were to contribute to the general literature on human decomposition and provide more information for obtaining accurate postmortem interval estimations. The research questions this study addresses are as follows:

1. Does fat mass, represented by BMI, affect the rate of early to advanced decomposition? In other words, is there a difference in decomposition rate in early and advanced decomposition based on TBS between BMI classes?
2. Is BMI in obese individuals an accurate predictor of fat mass in the whole-body donors used in this study?
3. Do individuals with higher lean body mass progress through decomposition in the same TBS sequence and ADD range as individuals with higher fat mass?
4. If fat mass affects decomposition, is this due to insect activity?
    a. Do maggots consume fat mass at the same rate as lean muscle mass?
5. How is the estimation of the postmortem interval affected if fat mass impacts the rate of decomposition and how is this relevant to forensic anthropology?

II. MATERIALS AND METHODS

To determine if fat mass affects the rate of decomposition, the Accumulated Degree Days (ADD) needed to reach skeletonization of the trunk (a TBS stage) for 25 whole-body donors from the Willed Body Donation Program at Texas State University were compared. The donors used in this study were unautopsied and were placed supine, unclothed, and under a cage on the surface at the Forensic Anthropology Research Facility (FARF) between 2019 and 2022 (Figure 1). FARF, operated by the Forensic Anthropology Center at Texas State (FACTS), is 26 fenced acres within Freeman Ranch in San Marcos, Texas (Gocha et al., 2022). The sample consists of 16 females and 9 males between the ages of 39 and 94 years old, with an average age of 68.72 years old. The sample demographics are shown in Table 2. The number of donors within each of the six BMI categories are listed in Table 3.

Figure 1. Donors used in this study were all unautopsied, placed unclothed, supine, and caged at FARF. Additional subcutaneous fat measurements were collected, and the incisions covered by tape.

Table 2. Sample Demographics including BMI Category, Sex, and Age.

Individual #	BMI Category	Sex	Age
1	Underweight	Male	84
2	Underweight	Female	79
3	Underweight	Female	86
4	Normal	Female	89
5	Pre-Obese	Female	66
6	Pre-Obese	Male	72
7	Pre-Obese	Female	80
8	Pre-Obese	Female	94
9	Pre-Obese	Male	73
10	Obese Class I	Male	57
11	Obese Class I	Female	39
12	Obese Class I	Male	62
13	Obese Class I	Female	82
14	Obese Class I	Female	54
15	Obese Class I	Female	62
16	Obese Class II	Female	68
17	Obese Class II	Female	40
18	Obese Class II	Male	86
19	Obese Class II	Female	69
20	Obese Class III	Female	83
21	Obese Class III	Female	64
22	Obese Class III	Male	66
23	Obese Class III	Female	62
24	Obese Class III	Male	53
25	Obese Class III	Male	48

Table 3. Number of donors in each BMI category.

BMI Category	Number of Donors
Underweight	3
Normal	1
Pre-Obese	5
Obese Class I	6
Obese Class II	4
Obese Class III	6
Total	25

Of these 25 individuals, retrospective decomposition data from 16 of the donors was collected through photographs and written notes. These 16 donors were all monitored until skeletonization of the trunk was reached and had accurate temperature data. Total Body Score was recorded by the author based on a series of daily photographs of the donors taken throughout the decomposition process, as TBS can be accurately assessed from pictures (see Appendix A) (Dabbs et al., 2016; Megyesi et al., 2005; Nawrocka et al., 2016).

The decomposition data from the remaining nine donors ("active donors" as opposed to retrospective analyses of past donors) was collected by the author in the form of photographs, notes, and TBS assessments in the field during the spring, summer, and fall of 2021 (see Appendix B). For these nine individuals, decomposition was monitored daily until there were no changes in TBS, then data collection was switched to every three days, weekly, and finally every two weeks depending on the state of decomposition and the placement of other donors. For these nine active donors, additional subcutaneous fat measurements were collected during the intake of the remains. The subcutaneous fat measurements were taken at the left mid-thigh, at the umbilicus, and five centimeters cranial to the umbilicus by making small incisions at the thigh and at the umbilicus and moving cranially. Subcutaneous fat was measured at the lateral thigh and anterior waist as those are the two areas of the body most fat is held. Two measurements were taken at the waist (at the umbilicus and five centimeters cranial to the umbilicus) as the formation of the umbilicus affected the amount of subcutaneous fat present on some individuals. Once subcutaneous fat at each location was measured, the incisions were glued back together and taped over (Figure 1) in order to mitigate the effects open wounds have on decomposition rate (Mann et al., 1990).

To calculate ADD, temperature data from the weather station located in FARF was obtained from MesoWest, operated by the University of Utah. Hourly temperature data was recorded and the average temperature for each day from 2019 to 2022 was calculated to determine the ADD from placement until skeletonization of the trunk was reached for each donor. The TBS stage of skeletonization of the trunk was used in this study as the trunk is the area that differs most between individuals of differing fat masses and BMI categories, and decomposition rate slows once that stage is reached.

To examine insect activity on the different body tissues, four 10-ounce (oz) tissue samples were obtained including skin, subcutaneous fat, muscle, and a cross-section of the three. The samples were placed in separate Mason jars and then in an open plastic container to ensure the samples remained upright and could not be accessed by terrestrial scavengers (Figure 2). The plastic container was placed at FARF, covered with a cage, and a tarp was placed over the top of the cage and secured with rocks to keep rainwater out. The samples were weighed and photographed daily for five weeks, until three consecutive days of reasonable temperatures passed with no insect activity, and then data collection was switched to every other day until a storm damaged the samples.

Figure 2. Tissue samples placed in Mason jars and in plastic container at FARF. The samples were then covered with a cage and tarp.

Statistical analyses examining BMI, TBS, ADD, and subcutaneous fat were performed in SPSS (IBM Corp, 2017). One outlier was identified and removed from statistical analyses (N = 24). To determine if fat mass, represented by BMI, affects the rate of decomposition, the ADD needed to reach the TBS stage of skeletonization of the trunk for 24 donors were compared using a Kruskal-Wallis Non-Parametric Test, as the assumptions of parametric tests (normal distribution, quality of variances, and independent variables) were not met by my sample. Because there are six BMI categories, and they are not evenly represented within the sample, ADD needed to reach skeletonization of the trunk between non-obese (underweight, normal, and pre-obese categories) and obese (obese classes I – III) individuals was compared using a Mann-Whitney U Test. To examine if BMI is an accurate predictor of fat mass in the sample of whole-body donors from which subcutaneous fat was measured, another Kruskal-Wallis Non-Parametric Test was performed. Measures of subcutaneous fat at the thigh and five centimeters cranial to the umbilicus were used in the statistical analyses as the measures of subcutaneous fat at the umbilicus were overall lower due to the pinching of the skin. No statistical tests were conducted using the tissue sample data as there was only one study trial run.

III. RESULTS

Fat Mass, Represented by BMI, and Decomposition Rate

The results of the Kruskal-Wallis Non-Parametric test comparing the ADD required to reach skeletonization of the trunk across the six BMI categories are illustrated in Table 4. Because the significance value is over 0.05 ($p = 0.131$), the null hypothesis that the distribution of ADD for trunk skeletonization is the same across BMI categories is retained.

Table 4. Kruskal-Wallis Test comparing ADD for Trunk Skeletonization and BMI. Results indicate ADD needed to reach skeletonization of the trunk does not differ across the six BMI categories.

Hypothesis Test Summary				
Null Hypothesis		**Test**	**Sig.** [a,b]	**Decision**
1	The distribution of ADD for Trunk Skeletonization is the same across categories of BMI.	Independent-Samples Kruskal-Wallis Test	0.131	Retain the null hypothesis.
a. The significance level is 0.050. b. Asymptotic significance is displayed.				

When the six BMI categories are collapsed into non-obese (underweight, normal, and pre-obese) and obese (obese classes I-III) categories, the significance value decreased to $p = 0.096$ (Table 5). Again, as the p-value is over 0.05, the null hypothesis is retained, indicating the distribution of ADD to reach skeletonization of the trunk is the same across non-obese and obese BMI categories. The potential trend seen here will be discussed further in the following chapter.

Table 5. Mann-Whitney U Test comparing ADD for Trunk Skeletonization and Obese vs. Non-Obese Individuals. Results indicate ADD needed to reach skeletonization of the trunk does not differ between non-obese and obese individuals but does indicate a trend towards significance.

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. [a,b]	Decision
1	The distribution of ADD to Reach Skeletonization of the Trunk is the same across Non-Obese and Obese BMI categories.	Independent-Samples Mann-Whitney U Test	0.096[c]	Retain the null hypothesis.

a. The significance level is 0.050.
b. Asymptotic significance is displayed.
c. Exact significance is the displayed for this test.

BMI as Predictor of Fat Mass

The distribution of subcutaneous fat at the thigh and five centimeters cranial to the umbilicus was compared across the obese BMI categories, as eight of the donors from which subcutaneous fat measurements were obtained were considered obese. The remaining donor was still included in the analyses as they were considered on the higher end of the pre-obese category (BMI = 28). Again, as the significance values for both subcutaneous fat at the thigh ($p = 0.469$) and five centimeters cranial to the umbilicus ($p = 0.204$) were greater than 0.05, the distribution of subcutaneous fat at both locations appears to be the same across the obese BMI categories (Table 6).

Table 6. Kruskal-Wallis Tests comparing fat locations and BMI. Results indicate the distribution of subcutaneous fat does not differ across the obese BMI classes.

Hypothesis Test Summary				
Null Hypothesis		Test	Sig. [a,b]	Decision
1	The distribution of Subcutaneous Fat at the Thigh is the same across Obese BMI categories.	Independent-Samples Kruskal-Wallis Test	0.469	Retain the null hypothesis.
2	The distribution of Subcutaneous Fat 5 cm cranial to the Umbilicus is the same across Obese BMI categories.	Independent-Samples Kruskal-Wallis Test	0.204	Retain the null hypothesis.

a. The significance level is 0.050.
b. Asymptotic significance is displayed.

Distribution of Subcutaneous Fat Between Males and Females

As males and females tend to carry weight differently, another two Mann-Whitney U Tests were performed to determine if there is a difference in the distribution of subcutaneous fat between obese males and females (Hattori et al., 1991; Siervogel et al., 1982). For both subcutaneous fat at the thigh ($p = 0.190$) and five centimeters cranial to the umbilicus ($p = 0.111$) the significance values are above 0.05, suggesting that the distribution of subcutaneous fat at both the thigh and five centimeters cranial to the umbilicus is similar between males and females in the obese BMI categories (Table 7).

Table 7. Mann-Whitney U Tests comparing fat locations and sex. Results indicate the distribution of subcutaneous fat does not differ between males and females in obese BMI classes.

Hypothesis Test Summary				
Null Hypothesis		Test	Sig. [a,b]	Decision
1	The distribution of Subcutaneous Fat at the Thigh is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	0.190[c]	Retain the null hypothesis.
2	The distribution of Subcutaneous Fat 5 cm Cranial to the Umbilicus is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	0.111[c]	Retain the null hypothesis.

a. The significance level is 0.050.
b. Asymptotic significance is displayed.
c. Exact significance is displayed for this test.

Differential Maggot Feeding on Tissue Samples

No statistical analyses were performed on the data collected from the maggot feeding study of the different body tissue types. However, the weight data, presented in Table 8, highlights how the maggots only consumed the muscle tissue, with no interest shown in the skin, fat or even cross-section sample. The results of this study have interesting implications that are addressed in the following section.

Table 8. Weight data for individual tissue samples. Starting weight for all samples was 19.10 oz.

Date	Muscle Weight (oz)	Skin Weight (oz)	Fat Weight (oz)	Cross-Section Weight (oz)
2/10/22	18.98	19.12	19.08	18.94
2/11/22	18.84	19.08	19.08	18.84
2/12/22	18.52	19.05	19.01	18.55
2/13/22	18.48	19.01	18.98	18.52
2/14/22	18.31	19.01	18.98	18.38
2/15/22	18.24	19.01	18.98	18.34
2/16/22	17.95	18.98	18.98	18.20
2/17/22	17.50	18.87	18.94	18.06
2/18/22	17.35	18.91	18.94	18.02
2/19/22	17.28	18.84	18.98	18.02
2/20/22	17.11	18.73	18.91	17.92
2/21/22	17.18	18.87	19.05	18.06
2/22/22	16.86	18.73	18.91	17.92
2/23/22	16.37	18.62	18.84	17.81
2/24/22	16.37	18.66	18.84	17.85
2/25/22	16.33	18.66	18.87	17.85
2/26/22	16.33	18.69	18.91	17.88
2/27/22	16.08	18.66	18.84	17.81
2/28/22	15.98	18.62	18.87	17.81
3/1/22	15.91	18.59	18.87	17.81
3/2/22	15.56	18.55	18.84	17.74
3/3/22	14.92	18.52	18.87	17.71
3/4/22	14.74	18.52	18.87	17.67
3/5/22	13.97	18.45	18.87	17.60
3/6/22	12.73	18.41	18.87	17.57
3/7/22	11.96	18.34	18.84	17.53
3/8/22	11.85	18.34	18.84	17.50
3/9/22	11.68	18.24	18.80	17.43
3/10/22	11.64	18.24	18.77	17.39
3/11/22	11.60	18.31	18.87	17.46
3/12/22	11.53	18.27	18.87	17.46
3/13/22	11.53	18.31	18.87	17.46
3/14/22	11.46	18.27	18.87	17.46
3/15/22	11.36	18.24	18.87	17.43
3/16/22	11.29	18.24	18.87	17.46
3/17/22	11.29	18.20	18.84	17.43
3/19/22	11.15	18.17	18.80	17.35

IV. DISCUSSION

The results of this study both support and differ from previous research surrounding body mass and decomposition (e.g., Ferreira & Cunha, 2013; Mann et al., 1990; Matuszewski et al., 2016; Roberts et al., 2017; Sutherland et al., 2013). Although none of the tests were significant, the results offer some important considerations for future decomposition research. Each test is discussed below, along with potential reasoning behind the results and study limitations. The data and research questions not addressed statistically are also examined.

Fat Mass, BMI, and Decomposition Rate

In the sample represented here, it does not appear that fat mass, represented by BMI, impacts the rate of early to advanced decomposition stages. When comparing the rates of decomposition across all six BMI categories, there is not a significant difference between the Accumulated Degree Days (ADD) needed to reach skeletonization of the trunk. Roberts et al. (2017), one of the only studies examining the relationship between body mass and decomposition that used human models, also found that body mass did not significantly impact decomposition rate. However, the Roberts et al. (2017) study examined the rate of decomposition throughout the entire decomposition process and was conducted in a different environment, which makes comparing the results of the two studies somewhat difficult. Furthermore, when the BMI categories were collapsed into non-obese and obese categories, the data begins trending towards significance, as shown in Table 5. These results indicate that although there was no significant difference in the ADD needed to reach skeletonization of the trunk in this small sample, there may be a difference in decomposition rate between non-obese and obese individuals and a larger sample size is needed to further examine the relationship between BMI and decomposition rate.

Additionally, this study only explored the effect of fat mass on decomposition rate in early to advanced stages of decomposition, due to sample and time limitations. Because the decomposition process in Central Texas results in mummification of the remains, decomposition usually stagnates with no skeletal exposure or very small amounts of skeletal exposure in certain areas (Parks, 2011). As such, donors must be monitored for long periods of time, and many of the retrospective donors examined did not reach skeletonization of the trunk during the time of monitoring, greatly reducing the study sample size. The sample was also not evenly distributed between the BMI categories, as many smaller individuals are used in other research projects due to ease of maneuvering and are thus not monitored for decomposition. Furthermore, both retrospective and active data was collected throughout the Covid-19 pandemic, which reduced the overall number of donors received by the Willed Body Donation Program (Gocha et al., 2022).

It was also found that BMI in obese individuals is not an accurate predictor of fat mass, as there was no significant difference in the amount of subcutaneous fat both at the waist and thigh of individuals in different obese classes (Table 6) or between obese men and women (Table 7). It is important to note that subcutaneous fat measurements were only taken in the obese (N = 8) and pre-obese (N = 1) groups, so no comparisons were made between individuals in the underweight or normal categories. Again, this is due to sample constraints, as none of the active donors available for this study fell in the underweight or normal BMI categories. These results likely indicate that once an individual is classified as obese, there is not a significant difference in the amount of subcutaneous fat an individual has or the storage location of the fat deposits. Further studies should collect data on the amount of subcutaneous fat for individuals in all the BMI categories in order to compare fat mass between all classes.

When determining if individuals with higher lean body mass progress through decomposition in the same TBS sequence and ADD range as individuals of higher fat mass, it is important to consider the decomposition process as a whole. Total Body Score, or the quantification of decomposition, is assumed to progress through certain stages, with every individual reaching each of those stages in a particular order. However, individuals often skip certain stages or may have active decomposition cease before certain stages are met. As previously discussed, the mummification process in Central Texas causes the decomposition process to stagnate in the advanced stages and obscures skeletal exposure, which is normally used to indicate the later stages of decomposition. The mummification process, coupled with time constraints, did not allow for statistical analysis of the rate of decomposition in advanced to late stages of decomposition, but differences in the rate of later decomposition stages were observed throughout the data collection process. It appears that individuals with higher BMI or fat mass remain stagnant at the advanced to later stages of decomposition for longer periods of time compared to individuals with less fat mass. For example, the largest donor in this study, (Individual 24: 413lbs, BMI = 60.1), required 18,036 ADD to reach skeletonization of the trunk, which is significantly longer than any other individual. These results are similar to those found by Sutherland et al. (2013), which noted little differences in the decomposition rates between large and small carcasses during early decomposition stages but found the decomposition rate of larger carcasses plateaued during the advanced decomposition stages while the decomposition of smaller carcasses either showed no plateau or a short plateau period. The results of the Sutherland et al. (2013) study, as well as the observed differences in decomposition described here, differ from those found by Roberts et al. (2017) and further emphasize the need for additional research to be conducted on the impact of fat mass on decomposition rate.

Maggot Feeding Behavior

Although no statistical analyses were performed on the tissue data, it was clear that maggots only fed on the muscle tissue sample, shown by the steady decrease in weight of the muscle sample compared to others (Table 8) and observed directly during data collection (Figures 3 and 4).

Figure 3. Active maggot feeding on tissue sample. Photo taken on 2/23/2022.

Figure 4. Overall photograph of tissue samples on 2/23/2022, showing maggot feeding activity present only on the muscle tissue. From left: muscle, skin, fat, cross-section.

These results are consistent with the mummification process that occurs in Central Texas, as there would be little to no skin left to mummify if it was consumed by maggots. Additionally, blowfly larvae die in high temperatures and prolonged sun exposure, so the skin acts as a protective layer as they feed on the muscle tissue. However, the results of the maggot feeding study are of particular interest because there was no statistically significant difference in ADD needed to reach skeletonization of the trunk between individuals with different amounts of fat, which would be expected based on the maggot feeding preferences shown here.

There are two proposed explanations for this phenomenon. First, the subcutaneous fat sample liquified when temperatures increased, and it is possible that fat on donors does the same thing, seeping out as part of the purging process and not affecting the consumption of other tissues by maggots. However, this suggestion only applies when temperatures are hot enough for the fat to liquify and would not explain differences seen during cooler temperatures. Secondly, there may be more overall muscle mass on the majority of individuals, even obese ones, that maggot feeding preferences have little effect on the decomposition process itself. An examination into the differences in gut microbiomes between obese and non-obese individuals was outside the scope of this research project, but it is important to note that these microbial differences would affect the early stages of decomposition. As there was no significant difference in the rate of early decomposition between the BMI classes, the differences in gut microbiomes between lean and obese individuals may not play a significant role in the decomposition process.

The results of the maggot feeding study contradict the findings of the statistical analyses. Maggot feeding mainly affects the rate of early to advanced stages of decomposition, where there appears to be no significant difference between the BMI classes. Subsequently, additional studies examining maggot feeding and its effects on decomposition rate should be conducted.

Implications for Postmortem Interval Estimation

The results of this study indicate that fat mass, represented by BMI, does not significantly affect the rate of early to advanced decomposition stages. Currently, it does not appear necessary to modify postmortem interval estimations (PMI) of early to advanced decomposition to account for an individual's fat mass, and investigators may continue to estimate PMI based on the data obtained from non-obese individuals. These data show that postmortem intervals may be accurately estimated in forensic contexts with the consideration of other factors, such as temperature and insect activity, rather than fat mass. However, as the data was trending towards significance, and some of the findings were contradictory, further research examining the more advanced stages of decomposition as well as the effect of maggot feeding behaviors on decomposition should be conducted to better understand these findings.

V. CONCLUSION

In this sample of whole-body donors, it appears that fat mass, represented by BMI, does not significantly affect the rate of early to advanced decomposition stages. Additionally, it does not appear that BMI in obese individuals is an accurate predictor of fat mass, or that there is a difference in fat deposit locations between obese men and women. The results of the statistical analyses, coupled with observations made throughout data collection, indicate that fat mass or body mass may not play a significant role in the rate of early to advanced decomposition stages, but may affect the rate of later decomposition stages. Although the results of the maggot study suggest that blowfly larvae do not consume fat mass, it appears that maggot feeding preferences do not impact the rate of early to advanced decomposition in individuals with differing fat mass amounts. Based on the results discussed here, it does not appear that postmortem interval estimations during early to advanced decomposition stages need to account for differences in fat mass.

Nevertheless, it is important to reiterate that this study has a relatively small sample size that is unevenly distributed among the BMI classes, and that, due to sample constraints, only the rate of early to advanced decomposition was examined. As other studies have noted, it appears that fat mass may in fact slow down the rate of later decomposition stages (Sutherland et al., 2013). Additionally, when the BMI categories were collapsed into non-obese and obese classes, the data indicated a trend towards significance. Further research examining the impact of fat mass on decomposition rate should be conducted through longitudinal projects involving more robust samples in order to fully understand the effect of fat on decomposition rate.

APPENDIX SECTION

APPENDIX A: TOTAL BODY SCORE GUIDE

Megyesi *et al.* Total Body Score Guide

Head and Neck

A. Fresh

(1pt) Fresh, no discoloration

B. Early decomposition

(2pts) Pink-white appearance with skin slippage and some hair loss.

(3pts) Gray to green discoloration: some flesh still relatively fresh.

(4pts) Discoloration and/or brownish shades particularly at edges, drying of nose, ears, and lips.

(5pts) Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present.

(6pts) Brown to black discoloration of flesh.

C. Advanced decomposition

(7pts) Caving in of the flesh and tissues of eyes and throat.

(8pts) Moist decomposition with bone exposure less than one half that of the area being scored.

(9pts) Mummification with bone exposure less than one half that of the area being scored.

D. Skeletonization

(10pts) Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.

(11pts) Bone exposure of more than half the area being scored with desiccated or mummified tissue.

(12pts) Bones largely dry, but retaining some grease

(13pts) Dry Bone

Trunk

A. Fresh

(1pt) Fresh, no discoloration.

B. Early decomposition

(2pts) Pink-white appearance with skin slippage and marbling present.

(3pts) Gray to green discoloration: some flesh relatively fresh.

(4pts) Bloating with green discoloration and purging of decompositional fluids.

(5pts) Postbloating following release of the abdominal gases, with discoloration changing from green to black.

C. Advanced decomposition

(6pts) Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.

(7pts) Moist decomposition with bone exposure less than one half that of the area being scored.

(8pts) Mummification with bone exposure of less than one half that of the area being scored.

D. Skeletonization

(9pts) Bones with decomposed tissue, sometimes with body fluids and grease still present.

(10pts) Bones with desiccated or mummified tissue covering less than one half of the area being scored.

(11pts) Bones largely dry but retaining some grease.

(12pts) Dry bone.

Limbs

A. Fresh

(1pt) Fresh, no discoloration

B. Early decomposition

(2pts) Pink-white appearance with skin slippage of hands and/or feet.

(3pts) Gray to green discoloration; marbling; some flesh still relatively fresh.

(4pts) Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities.

(5pts) Brown to black discoloration, skin having a leathery appearance.

C. Advanced decomposition

(6pts) Moist decomposition with bone exposure less than one half that of the area being scored.

(7pts) Mummification with bone exposure of less than one half that of the area being scored.

D. Skeletonization

(8pts) Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining.

(9pts) Bones largely dry, but retaining some grease

(10pts) Dry bone.

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APPENDIX B: DECOMPOSITION RECORDING FORM

DONOR #______________ TIME____________

DATE________________ INITIALS__________

TEMP/WEATHER____________ BMI___________

Flies	YES	NO
Maggots	YES	NO
Other insects	YES	NO
If yes, specify:		
Megyesi et al. Decomposition Score	Head & Neck ________ Trunk ________ Limbs ________ Total Body Score ________	
Marbling	YES	NO
Skin Slippage	YES	NO
Trunk Bloat	YES	NO
Hair Mat	INTACT PARTIALLY DETACHED COMPLETELY DETATACHED	
Cadaver Decomposition Island (CDI)	YES	NO
New Vegetation within CDI	YES	NO
Mold* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Skeletonization* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Scavenger activity* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	

DONOR #______________ TIME____________

DATE________________ INITIALS__________

TEMP/WEATHER____________ BMI___________

Flies	YES	NO
Maggots	YES	NO
Other insects	YES	NO
If yes, specify:		
Megyesi et al. Decomposition Score	Head & Neck ________ Trunk ________ Limbs ________ Total Body Score ________	
Marbling	YES	NO
Skin Slippage	YES	NO
Trunk Bloat	YES	NO
Hair Mat	INTACT PARTIALLY DETACHED COMPLETELY DETATACHED	
Cadaver Decomposition Island (CDI)	YES	NO
New Vegetation within CDI	YES	NO
Mold* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Skeletonization* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Scavenger activity* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	

DONOR #______________ TIME____________

DATE________________ INITIALS__________

TEMP/WEATHER____________ BMI___________

Flies	YES	NO
Maggots	YES	NO
Other insects	YES	NO
If yes, specify:		
Megyesi et al. Decomposition Score	Head & Neck ________ Trunk ________ Limbs ________ Total Body Score ________	
Marbling	YES	NO
Skin Slippage	YES	NO
Trunk Bloat	YES	NO
Hair Mat	INTACT PARTIALLY DETACHED COMPLETELY DETATACHED	
Cadaver Decomposition Island (CDI)	YES	NO
New Vegetation within CDI	YES	NO
Mold* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Skeletonization* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	
Scavenger activity* (select all that apply) *any amount present	NONE HEAD/NECK TRUNK LIMBS	

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