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**Author(s):** Giovanna M. Vidoli, Ph.D., Michael Kenyhercz, Ph.D., Dawnie W. Steadman, Ph.D.

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**Final Summary Overview**  
**Research and Development in Forensic Science for Criminal Justice**  
**Purposes**

**Grant # 2015-DN-BX-K019**

**Project Title: Expanding on Total Body Score with Use of Geographic**  
**Information Systems (GIS)**

Submitted by:  
Giovanna M. Vidoli, PhD  
Research Associate Professor, Anthropology  
865-974-1303; [gvidoli@utk.edu](mailto:gvidoli@utk.edu)

Co-Investigators:

Michael Kenyhercz, PhD  
Forensic Anthropologist and Scientific  
Recovery Expert  
Central Identification Laboratory  
Department of Defense POW/MIA  
Accounting Agency

Dawnie W. Steadman, Ph.D  
Director, Forensic Anthropology  
Center  
University of Tennessee, Knoxville

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The University of Tennessee  
1534 White Avenue  
Knoxville, TN 37996

Recipient Account #: R01-1005-460

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## **Purpose of the project**

New forensic anthropology methods in postmortem interval estimation must put into practice the suggestions of the National Research Council's report on strengthening forensic sciences in the United States (2009) and meet Daubert standards (*Daubert v Merrell Dow*, 1993) of scientific reliability. However, existing guidelines (SWGANTH 2013) do not explicitly aid the investigator in recording observations or assigning decomposition stages and consequently offers no direction on estimating the postmortem interval (PMI).

While there have been advances in attempts to quantify human decomposition (Galloway et al., 1989; Megyesi et al., 2005), none have taken a purely quantifiable approach from multiple specimens in the same conditions to document variability and hence, establish error rates. The Megyesi et al. (2005) trait list is comprised of quasi-continuous observations that are assigned scores based on decomposition stage. Observations scores are tallied for the head/neck, trunk, and limbs and then summed together to provide a total body score (TBS). Megyesi and colleagues (2005) have provided an equation that will allow a researcher to plug in the summed total body scores to estimate accumulated degree-days (ADD), and thus the post-mortem interval (PMI). In the Megyesi et al. (2005) scoring procedure, multiple traits are often listed under each observation. For example, in the limb scoring procedure, one of the observations scored consists of, "Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities." This example shows multiple traits (e.g., discoloration, drying) within a single observation, which may lead to confusion among

observers and thus low agreement. Further, Megyesi et al. (2005) do not address the issues of scavenging as it relates to decomposition.

The goal of the proposed project was to simplify and standardize decomposition observations to maximize agreement among observers and reduce bias. The standardization of decomposition observations was accomplished through the development of a list of easily identified traits that are recorded as present or absent and relied on the trait lists of Megyesi et al. (2005) as well as observations gained from a proof-of-concept pilot study. This study improves on the deficiencies of the Megyesi TBS method in that it uses empirical longitudinal data from donors with known PMI rather than photographs that had minimal temporal or contextual control. By placing multiple human donors at the same time in the same environment, direct observation of variation within and among individuals provide a more realistic and nuanced error rate. Moreover, the inclusion of a discrete list to independently score 16 regions of the body minimizes scoring bias inherent in the bilateral asymmetry of normal decomposition processes. Compiling a list of discrete traits (presence/absence) that can be scored in the field is then converted to an associated weighted score that ideally reduces bias and increases observer agreement. The addition of a scavenging observation adds the ability to document rapid tissue loss due to animal activity. Finally, the inclusion of GIS techniques allows for both the visualization and quantification of decomposition patterns through time with the use of heat maps and hot spot analysis.

## Project Subjects

Human donors from the Forensic Anthropology Center's (FAC) body donation program were selected based on: 1) known time of death; 2) natural cause of death with no external trauma; 3) donor weight between 150-250 pounds; and 4) not autopsied or embalmed. Each donor was placed in deep freeze for at least 24 hours to equalize body temperatures. Before placement, all donors were removed from the deep freezer and allowed to thaw to ambient temperature for at least 24 hours before each trial began. However, as seen in Table 1, some trials had fewer donors than others. The inclusion of the Fall Trials (Trials 3 and 7) was not part of the original research design but it did allow for more seasonal variability to be captured despite the small sample size for Fall 2016.

**Table 1. Project Subjects by Trial for 2015-DN-BX-K019**

<b>Trial: Season</b>	<b>Trial Start Date</b>	<b>Trial End Date</b>	<b>Number of days</b>	<b>Number of donors</b>
1: Spring 2016	7 April 2016	31 May 2016	55	10
2: Summer 2016	7 July 2016	30 July 2016	24	9
3: Fall 2016	30 November 2016	30 March 2017	121	3
4: Winter 2017	19 Feb 2017	9 May 2017	80	6
5: Spring 2017	29 April 2017	30 June 2017	63	5
6: Summer 2017	3 August 2017	24 September 2017	53	6
7: Fall 2017	13 October 2017	30 November 2017	49	6
8: Winter 2018	18 January 2018	3 May 2018	106	6
<b>TOTAL</b>				<b>51</b>

## Project Design and Methods

Each donor was scored with the trait list (Appendix B) and the data entered directly into a tablet. The use of the tablet in the field allowed for straightforward data collection and reduction of data transcription errors. For several trials, a second observer

collected data for two weeks to facilitate an interobserver study that further refines the trait list. Overall, in addition to the primary observer, there were seven secondary observers. Given the nature of the scoring procedure, direct comparison across all of the observations is not particularly useful to evaluate interobserver error. To this end, interobserver error was evaluated using the estimated ADD values from the random forest regression (see below) with a paired samples Wilcoxon signed-rank test. A Wilcoxon signed-rank test was employed over t-tests because the estimated ADD values are not normally distributed. Temperature data were recorded for each day from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). In accordance with Megyesi and colleagues (2005), all temperatures below 0° C were scored as 0° C because freezing and sub-freezing temperatures inhibit decomposition processes (Megyesi et al., 2005). Thus, data collected for each observation event included modified TBS for each region of the body and average temperature data for that particular day for each donor. Each donor was also photographed in a consistent pattern until the end of the trial.

## **Data Analysis**

At the conclusion of each trial, each of the regions of the body were submitted to random forest regression separately, which provided estimated ADD for each day of observation for each body part (see below for more detail). Individual homunculi were created for each day based on the estimated ADD scores and then combined to create a “heat map” that shows the progress of decomposition through time. Further, the individual heat maps were compiled for each season to visualize the overarching trends in

decomposition. This way, individual variation in decomposition as well as general, overarching patterns can be visualized. To test the significance of the heat map, hot spot analysis was employed. Hot spot analysis identifies the significant hot and cold areas in a given weighted feature set, which, in this instance is the estimated ADD for each body region, using the Getis-Ord  $G_i^*$  statistic (ESRI, 2011). The output of a hotspot analysis is a new layer showing the associated Z-scores and  $p$ -values projected on the homunculus.

Given the nature of progressive trait-suite expression, the data lends itself well to analysis through decision trees, specifically random forest modeling. Random forest models are an extension of traditional decision trees wherein at each decision node, or branch, a subset of random variables is tested and subsequent nodes are added to minimize overall error. The data were partitioned into three sets: a training set (a random subset of 70% of the data) to build the model, a validation set that tests the model as it is being created (a random subset of 15% of the data), and a testing set (a random subset of 15% of the data) that evaluated the completed model's performance on unused data. Random forest models were created from all of the data (all regions) and on individual regions. The models were created using known ADD, as calculated from the average daily temperature data from the NOAA from each trial period, as a function of each of the binary observations. The random forest model then predicts estimated ADD scores for the entire dataset, which can then be used to work backwards to estimate the time since death for an individual. The use of random forest models also allows for the prediction of new data. In addition to a predicted ADD estimate, a prediction interval is also generated, from the observed data itself, to aid practitioners into confidently reporting time since death estimates.

To evaluate model performance, plots of observed versus predicted ADD values were generated for each region of the body separately, and also the pooled observations. The  $r^2$  statistic, or coefficient of determination, was used to examine the relationship between predicted and observed scores. The  $r^2$  shows the proportion of variance in the target variable (in this instance ADD) that is predictable from the input variables (binary observations from each body region). The closer an  $r^2$  value is to 1.0, the better the model is at predicting future outcomes.

### **Project Findings**

There was no significant difference between the different observers' estimated ADD scores for each of the comparisons ( $W = 48$ ;  $p = 0.8017$ ). A table of  $r^2$  values for each body region from the final model (all trials combined) are shown in Table 2. The predictive power of the model is excellent with correlation of determinations ranging from 0.5273 (right foot) to 0.9271 (all regions). In comparison, the most optimistic  $r^2$  value reported by Megyesi et al. (2005) is 0.8456, which demonstrates the utility of using discrete observations over more generic weighted observations. Further, the scatter plots of the actual versus predicted values for each region show a plateauing of estimated ADD scores, typically around 1000 ADD. However, when all of the regions are considered together, the plateauing effect is removed, which indicates the importance of considering the body as a whole. Figure 1 shows the pooled observations over the course of all trials and 51 donors.



Table 2. Coefficients of determination ( $r^2$ ) by region for actual versus predicted ADD scores.

Region	$r^2$
All Regions	0.9271
Left Upper Arm	0.7527
Right Upper Arm	0.7509
Right Upper Leg	0.7507
Left Upper Leg	0.7415
Abdomen	0.7345
Head and Neck	0.7222
Left Lower Arm	0.7172
Chest	0.717
Left Lower Leg	0.7056
Genitals	0.6987
Right Lower Arm	0.6983
Right Lower Leg	0.654
Left Hand	0.6424
Right Hand	0.6194
Left Foot	0.5836
Right Foot	0.5273

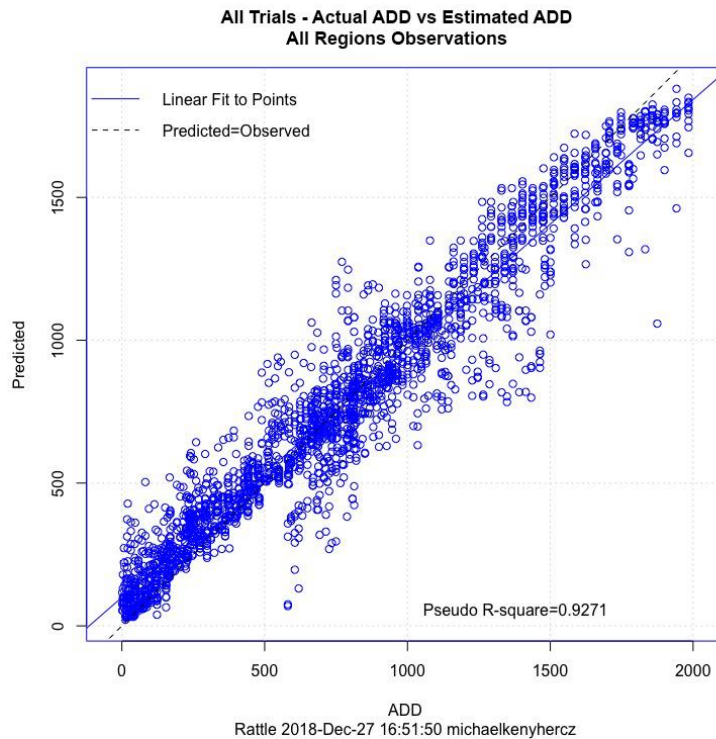


Figure 1. Predicted versus estimated ADD scores and resulting  $r^2$  values for all observations in all regions. The solid line indicates the linear model fit and the dashed line shows a theoretically perfect correlation.

The resulting hot spot analysis of the averaged estimated ADD scores shows the lower leg, right foot, head and neck, and chest have significantly lower estimated ADD values relative to the other regions of the body. Consistently, the hands and feet show the least decomposition relative to the rest of the body. The summed estimated ADD scores show a more general trend of the abdomen, genitals, upper arms, and upper legs decomposing more quickly than the rest of the body (Figure 2).

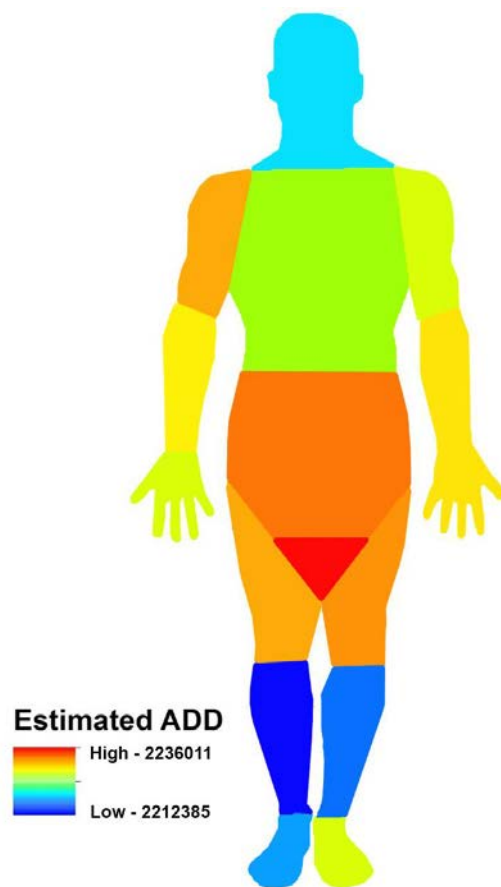


Figure 2. Estimated ADD values showing spatial trends in decomposition across the 16 different regions of the body for all donors in the study. Warmer colors (red) show greater decomposition than cooler colors (blue). Several binary variables were never observed, typically concerning the insect activity other than maggots at regions of the arms and legs.

The completed project elucidated several important outcomes for postmortem interval estimation. First, the addition of scoring individual, discrete traits, without any weight associated with it during collection allows for less bias, especially from practitioners that do not have much experience with decomposition. This is especially important because there are no instructions on which part of the composite observations in Megyesi et al. (2005) should be given more weight. Second, scavenging activity greatly accelerates decomposition around the scavenged region. Further, more precise observations are necessary. Adding in observations such as “color changes in distal aspect” or “color changes in proximal aspect” will aid in capturing more variability in limb decomposition, especially in earlier stages.

### **Implications for Criminal Justice System**

Estimating time since death and decomposition events is central to forensic science and the criminal justice system in the United States. The preliminary results have the ability to significantly impact medicolegal investigations by providing more empirically grounded and realistic estimates of time since death as well as a method to more reliably collect decomposition data in the field.

Creating a more holistic observation list that examines multiple regions of the body independently adds fidelity to the analysis and yields more accurate results. The results of our study directly impact the medicolegal community by more precisely estimating the PMI, accounting for more sources of error (differential decomposition of paired elements, for example), and producing known error rates. Further, the associated

error rates, which are based on scientifically-derived data, will allow for the modified TBS to be *Daubert* compliant (*Daubert v Merrell Dow*, 1993).

This research provides a standardized data collection protocol that includes trait observations in layman's terms. The straightforward observation is accessible to all practitioners regardless of experience or education level in evaluating decomposition. Simply scoring the presence or absence of discrete traits will remove any bias because the observer does not make any conclusion about the stage of decomposition – they simply score what is observed. The trait lists and associated scoring system will be made available to the law enforcement and scientific communities along with all of the observed longitudinal data to promote further testing in different geographic regions. To meet the demands of the medicolegal community, longitudinal studies of human decomposition in different geographic regions are paramount. The models created will be incorporated into a graphical user interface (GUI) that will be available as a downloadable application on a tablet or smartphone. This will allow practitioners to score each of the observations for a decomposing body and be provided with an estimated ADD point estimate and associated prediction interval.

## Appendix A. References

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## Appendix A. Trait List

The following body regions were scored independently from each other:

Head/Neck	Right Upper Arm	Left Upper Arm
Chest	Right Lower Arm	Left Lower Arm
Abdomen	Right Hand	Left Hand
Genitals	Right Upper Leg	Left Upper Leg
	Right Lower Leg	Left Lower Leg
	Right Foot	Left Foot

The following traits were scored as present or absent:

### Bloat

- No Bloating
- Visible Bloating
- Beginning Bloat
- Active Bloating
- Partial Deflation of Bloat
- Skin Deflated

### Skin Coloration

- Mottling
- ~<50% Darkened Skin
- ~>50% Darkened Skin

### Skin Appearance

- Dry skin, bones, cartilage
- Hair on scalp still attached
- Skin is taut
- Skin is glossy
- Skin sloughing off in a few areas
- Evidence of scavenging
- Skin is dry
- Hair on scalp has slipped
- Most soft tissue gone, but some flesh remains
- Skin sloughing off in large areas
- Some bone is showing
- Skin has collapsed around bone and outline of bone is visible
- Skin appears dark and moist
- Skin appears desiccated or mummified
- Skin is pruned/waterlogged

### Purge

- Purge is beginning
- Purge is apparent
- Soil is saturated/soil stained

### Insect Activity

- Foam Present at insect feeding sites
- Insects around mouth, ears, eyes, nose
- Ants and flies present
- Large number of maggots ~>50%
- Some maggots present ~10%-50%
- Eggs Present
- Maggots active in orifice or opening
- Maggots active in large areas
- Few or no maggots ~<10%