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Review of Estimation Models for Post Mortem Interval using Total Body Score and Accumulated Degree Days for Different Geographical Regions

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Authors' contributions

This work was carried out in collaboration between both authors. Author OMA wrote the first draft of the manuscript. Author LEO managed the literature searches. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Post mortem interval (PMI) is the period since death of human or animal remains upon discovery. The study of decomposition of remains in forensic sciences has grown tremendously in recent years, hence, a good number of studies have provided taphonomic data on the prediction of PMI of decomposing cadaver remains using variables such as accumulated degree days (ADDs) and total body score (TBS). Mathematically, ADDs is the summations of mean daily ambient temperatures from the possible time of death to date of discovery of remains. Total body score is a quantitative variable used to evaluate whole body qualitative changes in the decomposition of such remains. Quantitative methods have been shown to provide a more objective and standardized assessment of decomposition. However, the question of a universal PMI model has been a difficult one to

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answer because of environmental variations within and between various regions in the world such as temperature, humidity, and presence of scavengers. These variations make it difficult to establish precise timelines for decomposition stages based solely on qualitative assessments. Therefore, the purpose of this article is to quantitatively review the impact of accumulated degree days and total body score from decomposition processes on the estimation of PMI and an attempt will be made to provide PMI models from various researches around the world.

Keywords: Taphonomy; postmortem interval; cadaver; accumulated degree days; total body score.

1. INTRODUCTION

In a rapidly-increasing rates of outdoor crimes and deaths globally especially in parts of Africa and around certain regions of the world, various research have been ongoing on the best methods of PMI estimation. Some of the foremost studies were done using both human and animal cadavers in order to qualitatively evaluate the processes of decomposition [1–5]. Ethical concerns have limited the use of humans for this type of research prompting researchers to seek alternate to humans with the best possible results. The animal species that comes conveniently due to their physiologic proxy to human were rats, rabbits, dogs, and in most of the cases, pigs [6–9]. Pigs were better utilized due to similarities in skin texture, body hair and modes of nutrition, as well as intestinal composition of similar microbiota [9–11]. The purpose of this article is to provide recent updates by reviewing various predictive models as deduced from various researches based on the relationship between total body score and accumulated degree days in the estimation of postmortem interval in various geographical regions.

Upon arrival to a particular crime scene, one of the major duties of a forensic pathologist or anthropologist is to estimate the possible time since death (or post mortem interval) of discovered remains found in such area in order to help solve the case. In some cases where such experts are not present, the police would have to either rely on the ante mortem information as obtained from either eye-witnesses or onsite videos and other technological devices if found in or around the crime scene [12]. Despite having such information, solving these crime cases are usually met with certain difficulties that could arise either from inauthenticity of eye-witness information or technical problems relating to technological devices that were recovered – hence the need to develop scientific methods of estimating post mortem interval.

2. POSTMORTEM INTERVAL: REVIEWING THE EARLIEST METHODS OF ESTIMATION

The postmortem interval (PMI) of decomposed remains of humans and animals could be said to be the period taken from time of cessation of life to the time of discovery of such remains. From a forensic point of view, a clearer knowledge of the processes involved in the decomposition of these remains is directly proportional to the accuracy of estimating PMI for these remains [13,14]. These postmortem processes are hugely associated with both internal factors such as age, sex and body mass of these remains, and external factors like temperature, relative humidity, soil factors and insect activities [8,15–17]. Since decades ago, several researchers in the field of forensic science have employed a host of methods towards estimating PMI and the accuracy of predictions using some of these methods especially during the early hours of death have proven to be reliable overtime.

The early periods of death usually goes along with bodily changes that are observed in the eyes of the deceased victim. One of them is the breakdown of retinal blood vessels which could occur about thirty minutes to about three hours upon demise [18]. Later on, the intra-ocular pressure is significantly reduced to about 4 mmHg or a smaller amount inside six hours [19]. Other signs of early deaths include, corneal cloudiness, pale skin texture, and discharge of light gastric contents within two hours of death are some of the methods of knowing the time since death of the deceased [12].

Body temperature is arguably the earliest biological means of estimating PMI from cadaver remains [20–23]. During the early minutes upon death, there is a sharp increase in postmortem body temperature due to body cooling – which was followed by a drop in body temperature levels after about 3 – 4 hours [22]. In addition to biological methods, some of the original publications did acknowledge that entomological approaches were able to verify their reliabilities in PMI estimation [24–27]. Examples of the foremost insect families that were first discovered were members of the insect order, Diptera, including the Sarcophagidae and Calliphoridae families [27].

Based upon the use of biochemical methods, a report by Furuno and Komura [28] was one of the foremost studies to explain from their findings after analyzing cadaveric fluids emanating from the eyes of human corpses that changes in inorganic phosphorus content of aqueous humor could reveal the PMI of these remains provided that the elements that contributed to rectal temperature fluctuations were recognized. Subsequently, a similar study stated that upon immediate cessation of life of a human being, elevated levels of ammonium compounds in the vitrous humor were associated with environmental changes in temperature [29].

Building on the works of Furuno and Komura [28] and Van Den Oever [29], Henry and Smith [30] investigated the chemistry of these cadaveric fluids and discovered that there was a significant increase in the potassium content of vitreous humor with time between 12 hours to about 100 hours since death of the remains. They further added that there were varying levels of ammonia and magnesium contents of the vitreous humor, as well as fluctuations in potassium content of aqueous humor. From a chemical perspective, the application of gas chromatography was able to show that inflammable forms of hydrogen gas, as well as other gases such as carbon dioxide and methane were associated with putrefaction of remains after about 4 days postmortem.

Other methods of PMI estimation that were formed were morphological or cytological methods – which included changes in the appearances of certain bone marrow cells [31] skin discolorations (the skin of the deceased individual looking pale, with signs of hypostasis and rigor mortis), and muscular rigidity (with lips becoming dry and hardness of body regions) [32], and the degrees of skeletal mutilations due to actions of scavengers [33]. Experimentally, morphological changes in the shapes and sizes of red blood cells of rats as a result of their osmotic fragility measurements have been observed with the aid of an electron microscope [34].

3. THE PROCESSES OF TOTAL BODY DECOMPOSITION

Occurring about three hours after death, the algor mortis stage commences denoted by visible signs of body cooling which varies based on temperature fluctuations and this is followed by the rigor mortis [35]. Rigor mortis is characterized by muscle stiffness around the body due to an abrupt shortage in supply of oxygen, subsequently leading to loss of adenosine triphosphate (ATP) in muscle cells. This usually occurs between 12 – 24 hours after death. The final stage is livor mortis. Firstly, hypostasis develops as spots of discoloration within 30 minutes to 2 hours. Later, these spots coalesce into larger patches, which is evident by the presence of bluish-purple coloration around the skin due to gravitational pull of blood vessels [36,37].

In trying to ensure PMI accuracy during any forensic taphonomic research, it is necessary to take into account the factors that affect body decomposition and that such factors could be best understood when studied using both qualitative and quantitative approaches [38]. Qualitatively, PMI estimations are done in line with the gross morphological stages of decomposition of body or skeletal tissues as observed in the decomposing carcass. Sequentially, they were initially grouped into four – fresh, bloat, decay, and dry stages [6,15]. Payne [1] was arguably the first to examine the morphological changes that took place during the processes of decomposition using juvenile pigs – as other previous works made use of other animals that did not share similar body morphological attributes with humans as that of pigs. By supporting his findings with the degree of insectivorous activities taking place during decomposition, he was able to qualitatively access these changes thereby modifying the four-stage decomposition processes as earlier proposed in a study of decomposition of dog carcasses by Reed [6] into six (6) phases of cadaver decomposition using these juvenile pig carcasses which included, fresh, bloated, active decay, advanced decay, dry and remains stages.

Afterwards, a similar study done by Komar & Beattie [39] further improved on the Payne classification of decomposition stages by applying the use of adult pig carcasses based on the observations from their study that there were significant differences in decomposition patterns between adult and juvenile pig carcasses. Komar & Beattie [39] suggested a five-stage decomposition phases which comprised of fresh, bloat, active decay, advanced decay, and dry remains stages.

However, the Galloway et al. [40] classification of total body decomposition using human cadavers became the foundation for the development of total body scoring systems based on the observable changes as seen in the carcasses at different stages of decomposition. These stages of decomposition were further classified into five namely, fresh, bloat, active decay, advanced decay, and skeletonization [40]. The fresh stage of carcass decomposition is usually 0 – 5 day postmortem and is denoted by absence of discoloration and little or no insect activity. During bloat phase, bloating is manifested, with its slippery skin showing a gray-greenish discoloration and insect activities. The bursting of bloated skin concludes this phase occurring between 1 – 21 days postmortem. This is later followed by active plus advanced decomposition occurring between 3 days to 18 months; and visible signs include, moistly tissues, saggy flesh, caving in of thoraco-abdominal cavity, extensive insect activity, partial skeletal exposure in body regions and mummification. The final stage of skeletonization (2–9 months) shows bones with some body fluids present or tissue covering less than half of the skeleton, dry bones.

3.1 Total Body Score: Assessing Methods of Scoring Decomposition

The total body score (TBS) is a quantitative parameter that was established for the purpose of scaling the extent of progressive decay of cadavers [16]. By expanding on the Galloway et al. [40] classification using human cadavers, the total body score (TBS) technique was developed by Meygesi et al. [16], to quantitatively predict the time of death by scoring morphological changes as a result of decomposition from selected body regions – head and neck, trunk and limbs (Tables 1-3). Since its inception, the use of the Meygesi et al [16] method has been reported in countless taphonomic studies using animal carcasses.

Prediction of PMI using TBS system as formulated by Meygesi et al [16] was hugely dependent on a major factor called temperature in the form of accumulated degree days (ADDs). Despite the breakthrough study done by Meygesi and colleagues, it raised certain concerns, such as the ethical issues associated with the use of human cadavers and the burdens associated

Table 1. Scores of body decomposition and their morphological changes as observed in the head and neck region [16]

Decomposition steps	Morphological changes	Poins
Fresh	No signs of discoloration	1
Early decomposition	Pinkish appearance with skin slippage and small loss of hair	2
	Gray – greenish discoloration with some flesh still relatively fresh	3
	Brownish discoloration, dryness of nose and ears.	4
	Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present.	5
	Brown – black discoloration of flesh	6
Advanced decomposition	Caving in of the flesh and tissues of eyes and throat.	7
	Moist decomposition with bone exposure less than one half that of the area being scored	8
	Mummification with bone exposure less than one half that of the area being scored	9
Skeletonization	Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue	10
	Bone exposure of more than half of the area being scored with dessicated or mummified tissue	11
	Bones largely dry, but retaining some grease	12
	Dry bone	13

Table 2. Scores of body decomposition and their morphological changes as observed in the trunk region [16]

Decomposition steps	Morphological changes	Points
Fresh	No signs of discoloration	1
Early decomposition	Pinkish appearance with skin slippage and presence of marbling	2
	Gray – greenish discoloration with some flesh still relatively fresh	3
	Bloating with green discoloration and purging of decompositional fluids.	4
	Post-bloating upon emission of abdominal gases, with discoloration changing from green to black.	5
Advanced decomposition	Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity	6
	Moist decomposition with bone exposure less than one half that of the area being scored	7
	Mummification with bone exposure less than one half that of the area being scored	8
Skeletonization	Bones with decomposed tissue, sometimes with body fluids and grease still present	9
	Bone exposure of more than half of the area being scored with dessicated or mummified tissue	10
	Bones largely dry, but retaining some grease	11
	Dry bone	12

Table 3. Scores of body decomposition and their morphological changes as observed in the limb region [16]

Decomposition steps	Morphological changes	Points
Fresh	No signs of discoloration	1
Early decomposition	Pinkish appearance with skin slippage on hands and/or feet	2
	Gray – greenish discoloration, marbling, with some flesh still relatively fresh	3
	Discoloration and/or brownish shades, particularly at edges, drying of fingers, toes, and other extremities	4
	Brown to black discoloration, skin having a leathery appearance	5
Advanced decomposition	Moist decomposition with bone exposure less than one half that of the area being scored	6
	Mummification with bone exposure less than one half that of the area being scored	7
Skeletonization	Bones exposure over one half of the area being scored, some decomposed tissue and body fluids remaining	8
	Bones largely dry, but retaining some grease	9
	Dry bone	10

with acquiring them for research purposes, and most importantly, negligence of some factors that are closely associated with decompositional process such as arthropod activity, as well as possible ecological variations in different geographical regions. Based on that, a lot of other studies that followed were proposing amendments to the Meygesi scoring method.

A research by Adlam and Simmons [7] was set out to modify the Meygesi TBS scoring method in their evaluation of the influencing factors that cause continuous morphological distortions of soft body tissues during decomposition of rabbit cadavers. One of those distortions observed were the loss of fur in these rabbit carcasses - which was proven to be a relevant factor during the assessment of TBS in the early periods of decay. Furthermore, another reason for modifying the Meygesi et al TBS scoring system as stated by Adlam and Simmons [7] was that they felt that the scoring system did not appreciate the actions of insects in the decay process of remains. This prompted them to develop their total body scoring system as observed during the decomposition of rabbit carcasses in their study as shown in Tables 4, 5 and 6.

In an African-based research, Myburgh and associates [41] did a study to possibly validate the Meygesi method using pig remains. It was found that albeit the use of pigs as human analogues was recommendable; their study did not completely validate the use of the Meygesi scoring system in the accurate estimation of PMI as they suggested that differences in seasons among regions could contribute to varying taphonomic processes. Nevertheless, a study completed by Moffatt et al. [42] detected statistical significant deficiencies in the Meygesi scoring scale upon analysis of their study results.

Table 4. Scores of body decomposition and their morphological changes as observed in the head and neck region [7]

Decomposition steps	Morphological changes	Points
Fresh	Fresh, no discoloration	1
Early decomposition	No skin discoloration, maggots visible	2
	Some flesh relatively fresh, fur loss	3
	Discoloration, brownish, drying of nose and ears, and heavy maggot activity	4
	Purging of decompositional fluids, wet flesh	5
	Skin brown to black	6
Advanced decomposition	Caving in of flesh and tissues of eyes and throat.	7
	Wet decomposition, bone exposure <50% scored area	8
	Dessication, bone exposure <50% scored area	9
Skeletonization	Bone exposure >50% scored area, wet tissue	10
	Bone exposure >50% scored area, dessicated tissue, incisor loss, and disarticulation	11

Table 5. Scores of body decomposition and their morphological changes as observed in the abdominal region [7]

Decomposition steps	Morphological changes	Points
Fresh	Fresh, no discoloration	1
Early decomposition	Skin appears fresh, fly eggs, few maggots	2
	Flesh appears red-brown, small amount fur loss (<30%)	3
	Bloating, purging of decompositional fluids, heavy maggot activity	4
	Bloat lost, severe fur loss (>70%), heavy maggot activity	5
Advanced decomposition	Wet decay, abdominal collapse where internal structure lost, flesh grey green	6
	Wet decay, bone exposure <50% scored area	7
	Surface mummification, bone exposure <50% scored area	8
Skeletonization	Black skin, bones greasy, body fluids occasionally present	9
	Bones with dessicated black skin over <50% scored area	10
	Bones largely dry and white, mummified skin	11
	Bones beginning to weather	12

Table 6. Scores of body decomposition and their morphological changes as observed in the limb region [7]

Decomposition steps	Morphological changes	Points
Fresh	Fresh, no discoloration	1
Early decomposition	Flesh appears fresh, some maggots	2
	Some flesh still fresh, fur loss	3
	Discoloration of skin to brown, drying of extremities	4
	Black skin, leathery appearance	5
Advanced decomposition	Wet decomposition, bone exposure <50% scored area	6
	Wet decomposition, some disarticulation	7
Skeletonization	Bone exposure >50% scored area, dry papery skin	8
	Bones largely dry and disarticulating	9
	Bones dry and white	10

They recommended an improved equation for the estimation of ADD, as well as recommended a then-new pattern of scoring the first stage of decomposition beginning at zero (0) as a replacement for three (3) – which they concluded would improve PMI estimation. This scale remained in usage until another similar study done by Keough et al. [43] sorted out to improve the TBS technique that was developed by Meygesi et al. [16] using pig cadavers as human analogues. Keough et al. [43] witnessed significant dissimilarities between pig and human bodies during the initial stages of decomposition such as, visible signs of lividity during fresh decomposition stage in pigs, skin colour differences in neck and trunk regions during bloat stage (darkish-red in pigs and grayish-green in humans), loss of body hairs and advent of maggot-filled sores at the conclusive stages of early decomposition, thereby prompting them to suggest a modification of the Meygesi TBS scale for pig cadavers. Their study did not observe differences in the morphology and successive processes of decomposition during advanced decomposition and skeletonization stages. Their proposed scoring system maintained the scoring patterns of the Meygesi TBS system (1 – 13 for head and neck region, 1 – 12 for trunk region and 1 – 10 for limb regions), on the other hand, they recorded observable changes as seen in fresh and early stages of pig decomposition (as shown in Tables 7-9). Further studies supported the Keough TBS scale as they were able to prove that the use of the Meygesi TBS scale to equate the rates of human and pig decomposition was shown to be statistically inappropriate [44,45].

Table 7. Scores of body decomposition at fresh and early stages and their morphological changes as observed in the head and neck region [43]

Decomposition steps	Morphological changes	Points
Fresh	No discoloration; with minor lividity in form of pinkish-red	1
Early decomposition	Pinkish appearance with no skin slippage and hair loss; Insect activity; a sharp pink or red form of lividity	2
	No grayish-green discoloration; dark-red discoloration with some flesh still relatively fresh; odema of ears; maggot colonization (mouth); initial bloating of neck and skin slippage	3
	Brownish discoloration, no drying of nose, ears, and lips; prominent bloating of neck; maggot colonization (mouth and eyes); purging of decomposition fluids (mouth).	4
	Purging of decomposition fluids out of eyes, ears, nose, mouth; brown discoloration; hair loss and skin slippage; drying of lips, nose and ears.	5
	Black discoloration of flesh; extensive maggot colonization and migration	6

Table 8. Scores of body decomposition at fresh and early stages and their morphological changes as observed in the trunk region [43]

Decomposition steps	Morphological changes	Points
Fresh	No signs of discoloration, with a slight pink lividity	1
Early decomposition	Skin appears shiny/glossy with early bloating and may show purple-black discoloration over abdominal area	2
	Gray-purple to green discoloration: some flesh still relatively fresh; marbling of abdomen with maximum bloat	3
	Purple-black discoloration and purging of decompositional fluids; skin slippage with maggot-filled blisters present; hair loss	4
	Postbloating following release of the abdominal gases, with extensive skin slippage and drying out of blisters	5

Table 9. Scores of body decomposition at fresh and early stages and their morphological changes as observed in the limb region [43]

Decomposition steps	Morphological changes	Points
Fresh	No signs of discoloration, with a slight pink lividity and rigor present	1
Early decomposition	Pink-white appearance with bloating of proximal parts of limbs	2
	Gray to green discoloration: marbling and shiny appearance of skin; some flesh still relatively fresh; skin slippage and hair loss	3
	Discoloration and/or brownish shades particularly at edges, drying of skin (starting distal to proximal).	4
	Brown to black discoloration, skin having a leathery appearance	5

4. TEMPERATURE (OR ACCUMMULATED DEGREE DAYS)

Temperature as an environmental factor has shown a high reliability in the prediction of post-mortem interval (PMI) across different regions [46,47]. It is impacted by a variety of factors such as seasons, elevation, scope, deepness of burial, water or moisture availability, moving air, vegetation, and presence of clothing [48]. The effect of temperature on the degree of cadaver decomposition has been applied scientifically upon the introduction of the accumulated degree days (ADD) method [16,49].

Accumulated degree days (ADDs) are mathematically expressed by the summations of daily average temperatures between dates of body discovery. A degree day is defined as one entire day where the temperature stays above the threshold by 1ºC. According to Vass [50], ADD ought to be measured in degree Celsius (ºC) and likely to reveal the ordinary temperature at the site corresponding to the date the corpse was found, or the temperature at the scene adjusted by a comparison of several days to any country's nearby local meteorological station.

The rate at which total body decomposition occurs and influences PMI is a function of the temperature of the decomposition environment in the form of accumulated degree days (ADDs) [51]. There is overwhelming evidence that thermal differences in geographical regions correlate with the rate of decomposition of remains [52]. Vass [50] further corroborated the significance of ADDs and suggested a universal formula for PMI estimation irrespective of differences in environmental conditions. Vass studied both surface and burial decompositions of human corpses for 20 years at the University of Tennessee's Anthropology Research Facility in the United States and gathered daily weather records of temperature, humidity and rainfall, as well as other variables such as soil moisture and adipocere. Results from his study postulated two formulas representing the different forms of decomposition in order to predict PMI;

i. $$PMI_{surface} = \frac{1285 \times (decomposition/100)}{0.0103 \times temperature \times humidity}$$

ii. $$PMI_{burial} = \frac{1285 \times (decomposition/100) \times 4.6 \times adipocere}{0.0103 \times temperature \times soil\ moisture}$$

However, a related study by Cockle and Bell [53] concluded that no universal formula could significantly estimate PMI – which contradicts the study mentioned by Vass [50]. According to the study by Vass [50], soft tissue decomposition of human corpses was evaluated using a scale of 1 – 100%. An additional flaw to Vass study was recommending a formula as a general model for PMI estimation in other regions based on the environmental factors associated with the studied area. Cockle and Bell [53] established from their investigation that the formulas proposed by Vass [50] could not be effectively useful to cases as observed in their Canadian study site.

5. EVALUATING STUDIES OF PMI ESTIMATIONS USING TBS AND ADDS: QUANTITATIVE DIFFERENCES IN PREDICTIVE MODELS IN SELECTED GEOGRAPHICAL REGIONS

For research purposes, the use of multivariable regression models involves the assortment of various data variables and analyzing the relationships between predictor variables and the outcome variables by developing mathematical expressions [54]. In line with the regression model developed by Meygesi et al [16], the prediction of ADD using TBS was stated as;

$$ADD = 10^{(0.002 \times TBS \times TBS + 1.81)} \pm 388.16$$

The above Meygesi method suggested a coefficient of determination of 68%. Since the study done by Meygesi and his colleagues, however, several predictive models have been developed across various regions.

5.1 Asia and Australia

In an Australian-based study done by Marhoff et al [55] using four pig carcasses, the estimation of ADD was done upon the application of the method of scoring total body decomposition as developed by Meygesi et al [16]. Findings from their study revealed that their developed regression model for predicting ADD was;

$$ADD = -85.8 + 39.7(TBS)$$

However, the line of best fit model as deduced by Marhoff et al. [55] had an accuracy of 20%.

5.2 Europe

Probst et al. [56] reported from their comparative study using both pig and boar carcasses as human analogues in a cadaver decomposition island (CDI) located in the German city of Reims, that at 5 – 6 day postmortem (106 ADD) having reached the bloat stage of decomposition, the pig carcasses began to de-bloat on the 9th day of postmortem (160 ADD) while the boar carcasses commenced de-bloating at day 33 postmortem (539 ADD). Furthermore, with a TBS score of 17 at 28 weeks postmortem, the trunk region of the pig entered the stage of skeletonization with an ADD value of 1527.

The scoring of TBS_{surf} (as it relates to surface burial of cadavers) by Moffat et al [42] was designed to start from 0 to 32 instead of the unique scoring system of 3 to 35 (as proposed by Meygesi et al method), as they postulated that the state of no decomposition is more logically quantified by zero. Moffat et al. [42] applied the inverse prediction table for estimating ADD and this resulted in the regression formula that produced a coefficient of determination of 91%, indicating that study estimates were generally closer to the actual data points. The equation is as follows;

$$TBS_{surf} = (125 \times log_{10}ADD - 212)^{0.625}$$

In applying the total decomposition score (TDS) to predict ADD using human cadavers, Geldermann et al. [57] reported that their R-squared value (R^2) decreased significantly to 56% from 66%, and the prediction formula was

$$ADD = 10^{(0.03 + 0.19 \times TDS)}$$

The reliability of ADD in PMI estimation is a challenging one due to the fact that the processes of decomposition could differ when comparing outdoor and indoor remains. This is because indoor remains have shown to have a lesser decomposition rate as it is not heavily influenced by external variables [52].

The study by Simmons et al. [52] conducted in a northeastern region in England investigated different types of decomposition using *Sus scrofa* pigs and developed several regression formulas for each of them. Their study showed that at an accuracy of 62%, the respective regression equations for outdoor and indoor decompositions were:

$$TBS\ (outdoor) = -13.07 + 12.15 \log ADD$$

$$TBS\ (indoor) = -0.97 + 6.12\ \log ADD$$

At an R^2 value of 0.75 (prediction accuracy of 75%), the corresponding regression equations for burial and surface decompositions were:

$$TBS\ (burial) = 4.48 + 4.14\ \log ADD$$
$$TBS\ (surface) = -20.36 + 15.02\ \log ADD$$

After applying the deduced equation for predicting PMI as provided by Megyesi et al. [16], a related study done by Suckling et al. [58] noted from their results that the equation could not be statistically reliable for predicting PMI as their study had a standard error (SE) of estimate of ±787.71 ADD as opposed to the SE of estimate of ±388.16 ADD.

5.3 Africa

In agreement with a study by Sutherland et al. [59] on the influence of body size on prediction of PMI using ADD, the average ADD needed for smaller pigs to reach skeletonization was 875.38 ADD, while the larger ones attained skeletonization at an average of 2400.85 ADD.

A study done by Myburgh et al [41] applied a linear regression by means of log transformed data in order to develop a formula. The implication of the formula was that its accuracy in predicting ADD with respect to TBS in the study could only account for about 62% (with an R^2 of 0.623). This enabled them to deduce a predictive equation that could be used to estimate the ADD of an unidentified carcass that was mathematically expressed as;

$$ADD = 10^{(0.073 \times TBS + 1.135)}$$

In a study conducted in a South African region, it was reported from their regression analysis that TBS had an R-squared value of 0.6894 when predicting PMI using buried remains, while that of surface remains depicted an R-squared value of 0.474, leading the researchers to conclude that TBS and PMI did show a moderate relationship for buried remains as opposed to surface remains [60]. However, Marias-Werner et al. [60] further noted that upon plotting TBS against ADD, the R^2 value significantly boosted for surface remains to 49% and dropped for buried remains to 61%.

5.4 North and South America

The outcomes of a study by Giles et al. [61] established that both TBS models could calculate estimated ADD with high confidence value (at $R^2 = 0.9$), pointing out that 90% of the unevenness in the decomposition scores were accredited to accumulated temperature values. An investigation by Forger et al [62] upon the application of the Meygesi TBS scoring system explained that when the estimated ADD from TBS is used to derive an estimated PMI, with an accuracy of 95%. Also, significant differences between the estimated and actual PMI are usually observed, which further buttresses the application of ADD-derived PMI estimation models for medicolegal purposes.

As explained by Dautartas et al. [45] in a study conducted in an outdoor laboratory in Tennessee, United States, these differences are subject to variations in body size and microbes as specific to the decomposing remains, whether human or non-human. Here, the accuracies in predicting ADD with respect to TBS in their study could account for 100% for humans and 80% for pigs. In addition, experimental studies have portrayed that temperature affects body decomposition and PMI estimation variably based on the form of burial [4,60,63].

6. FACTORS THAT INFLUENCE BOTH TBS AND ADDS IN PMI ESTIMATION

The action of insects during decomposition have been shown to possibly influence the accuracy the estimation of time of death in relation to environmental temperature within the decompositional environment [64–66]. Varying insect (or arthropod) species first inhabit, grow and later move off from decomposing remains at different time intervals commonly called minimum postmortem interval (minPMI) thereby inducing the rate of their decay process [67–69]. Despite the presence of the most commonly found insects found in such remains such as the blowflies and houseflies, and other insect species have shown to differ among geographical regions because of their thermal environmental differences [56,70,71]. Hence, the role of forensic entomology in the estimation of time of death at the early stages of decomposition has proven to be a reliable forensic tool.

Finally, several studies done on the impact of temperature and the level of body decomposition on the soil chemistry within various CDIs have suggested that there are early upsurges in soil pH due to the ammonification of proteins and other organic nitrogen sources from the decomposing fleshy remains [7,72–75]. Vass et al. [49] reported an increase in pH under human remains at 750 ADD and later dropped to control soil values at nearly 3750 ADD and further declining to below control soil values up to 4500 ADD. Wilson et al. [76] also reported increased pH from 4.6 to 7.2 during their monitoring of buried pigs up to 378 days whereas the study by Pringle et al. [77] revealed so much variability in pH among decomposition islands under pigs - although, they conclude that their study were not validate their observation towards predicting PMI.

7. CONCLUSIONS

Undoubtedly, temperature (in form of accumulated degree days) has been known to play a significant role in total body decomposition and could be highly reliable in the prediction of postmortem interval of cadaver remains. Meanwhile, from a quantitative point of view, it is of utmost relevance for researchers to understand how variations in ambient temperatures across regions affect the rate at which these remains decompose while applying total body scoring methods.

Furthermore, this review compared regression models among various related taphonomic studies and concluded that there is no universal formula for estimating PMI using both ADDs and TBS, instead, the differences in these models seek to buttress diversities in global ecosystems. The accuracies of prediction models developed in parts of Asia and Australia were less significant compared to other geographical regions.

8. RECOMMENDATIONS

This review recommends that future researches in forensic taphonomy should try to validate the accuracies of prediction models that have been developed in various geographical regions. Also, the formulation and validation of models pertaining to the type of burials across these regions should be carefully considered since the roles of edaphic factors are known to influence cadaver decomposition.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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