REVIEW ARTICLE

Estimation of Post Mortem Interval using Accumulated Degree Days (ADD) Method

Arif Wahyono[1,2], Denys P. Alim[1,2]

[1] Faculty of Medicine, Universitas Islam Negeri Syarif Hidayatullah, Jakarta, Indonesia
[2] Installation of Forensic Medicine and Medicolegal Studies of Raden Said Sukanto Bhayangkara Tertiary Hospital, Kramat Jati, 13510, Indonesia

ABSTRACT

Estimation of postmortem interval is an integral part of a medicolegal death investigation. Nonetheless, advanced post-mortem changes made such estimation complicated because various factors affect the rate and process of decomposition. The main factors are the temperature and humidity within a distinct region and also other factors such as clothing and the presence of wounds. Each geographic area has its characteristic temperature and humidity which make the decomposition rate differs from one place to another. The Accumulated Degree Days method uses the heat-time unit as an indicator for estimating the decomposition rate by calculating the mean temperature during the day and subtracting it from the threshold temperature. The accumulated degree is then converted into a period for how long the body has been dead. This method showed an accurate and reliable result when used for estimating postmortem interval.

Keywords: Accumulated Degree Days, Estimation, Forensic, Post-mortem Interval

Corresponding Author:
Arif Wahyono, MD
Email: forensik.rspolri@gmail.com
Tel: +62-21-74716718

INTRODUCTION

According to the Indonesian Law of Health Number 36 the year 2009, death is defined as the irreversible cessation of cardiovascular and respiratory systems or if brainstem death is proven. In the case of an unidentified dead body, an effort must be made to identify the dead body. The central and regional government bodies with help from the society are held responsible for the effort (1). In the field of forensic medicine, a forensic doctor commonly receives unidentified dead bodies that are suspected of unnatural deaths. During a medicolegal death investigation, estimation of postmortem interval is often inquired about by the police aside from the cause and mechanism of death. An accurate and reliable post-mortem interval aids the police to understand the circumstances regarding the death and also helps to eliminate suspects if their alibi is valid for when the death occurred (2,3). The estimation of post-mortem interval can be acquired from eyewitness testimony or antemortem evidence such as the usage history of electronic devices or video footage. However, eyewitness testimonies are often inconclusive and antemortem evidence is not necessarily available during the investigation. Therefore, estimation of postmortem interval relied heavily upon the postmortem changes present in the body. Thus, every doctor, especially forensic doctors, should have prior knowledge regarding the process of decomposition to help them aid the medicolegal investigation by providing an accurate estimation of postmortem interval (2).

The segmentation of retinal blood vessels, which typically occurs within 30 minutes but can occasionally take up to two hours after death, loss of intraocular pressure, which reaches 4 mmHg or less within six hours of death, clouding of the cornea within two hours of death, and emptying gastric contents, where small, light meals get emptied from the stomach within one to three hours after death are additional methods to estimate the post mortem interval during the immediate stage after death. However, post mortem interval measurement during immediate alterations typically indicates a lack of perceptible morphological or histochemical changes (4).

Some other literature also has described the use of early post-mortem changes such as livor mortis, rigor mortis, and algor mortis to estimate post-mortem intervals but these early changes have limitations when used as a single indicator for estimating post-mortem intervals (5). In Indonesia as a tropical country with a warm climate (mean overall temperature between 230C and 330C),

it is very easy for the decomposition process to occur. In addition, Indonesia's geographical area is very wide and in the form of an archipelago, making it longer and more difficult for a dead body to be found. Therefore, many cases sent for the forensic examination have already undergone advanced post-mortem changes and made the early post-mortem changes unusable to estimate the post-mortem interval. As the post-mortem changes advance, the estimation of post-mortem interval becomes more difficult because many factors influenced the decomposition process. Qualitative observation of the decomposition process yields inaccurate and imprecise post-mortem estimation (2,5).

The process of human remains decomposition is a complex biochemical reaction that started when someone is declared dead. Decomposition underwent five stages which are fresh stage, bloat stage, early decomposition, advanced decomposition, and skeletonization. Factors affecting the rate of decomposition are temperature and humidity, pH, and oxygen, as well as direct sunlight, presence of wounds, and insect colonization. It is believed that temperature and humidity are the main factors that affect the rate of decomposition, therefore it is crucial to have meteorological information regarding the temperature and humidity of a certain region where the crime scene took place (2). The difference in temperature and humidity between regions yields different rates of decomposition unless they are similar in temperature and humidity as they directly influence the rate of decomposition (6). In accordance with providing scientific and accountable post-mortem interval estimation, we need a certain method that can estimate the post-mortem interval accurately despite the advanced post-mortem changes, and Accumulated Degree Days (ADD) is one such method.

ACCUMULATED DEGREE DAYS METHOD

Accumulated Degree Days (ADD) is a method that combines the thermal energy unit and a certain chronological period time unit which is then presented as an accumulation of degree days. Thermal energy is heat that is needed for the biochemical process to take place during the decomposition process. ADD calculate the thermal energy accumulated inside the body within a certain period, therefore, it should give an equal amount of expected post-mortem changes based on calculated ADD. This method makes the differences in temperature and humidity between different regions comparable as it turns the unit into a universal heat-time unit (7).

An original article by Megyesi, et al on 68 decomposing bodies revealed that the stage of decomposition can give valuable information regarding the time of death, especially when the decomposition is treated as a continuous variable and analyzed together with ADD method. Megyesi et al classify decomposition into four categories; the fresh stages, early decomposition, advanced decomposition, and skeletonization. Each class has subcategories with their corresponding score. The decomposition is then evaluated from three regions: from head and neck, trunk, and limbs, which yields a collective score termed Total Body Score (TBS) which ranged from 3 to 35 points (Table I). The TBS has a good correlation with ADD in a logarithmic fashion and Megyesi et al also noted that approximately 80% of the variation during the decomposition process was attributed to ADD (8).

$$\mathrm{ADD_{thd}} = \left[\frac{\{Tmin+Tmax\}}{2}\right] - threshold$$

ADD score is calculated from the mean of the highest and lowest temperature during that day and then subtracted by the threshold temperature which is needed for the biochemical process of decomposition to take place (9). The ADD for that day then accumulated with the previous chronological days to yield accumulated degree days. According to the ADD, the estimation of post-mortem interval can be made for certain decomposition process/ post-mortem changes that have taken place. The ADD method uses temperature as an independent variable in relation to the time of death as the dependent variable in estimating the post-mortem interval (7,8).

This TBS scoring system gives a quantitative score of decomposition on the body from which the ADD can be calculated. The research by Megyesi et al is then corrected and developed further by Moffatt et al using the original data set but with improved eligibility criteria and better statistical calculation. The result of Moffatt et al gives an equation relationship between TBS and ADD as follow (10):

$$TBSsurf^{1.6} = 125\ x\ Log_{10}ADD - 212$$

$$\text{or TBSsurf} = (125 \text{ x } Log_{10}ADD - 212)^{0.625}$$

Moffat et al produced a coefficient of determination between TBSSurf and ADD of 0.91 which means that almost all variation during the process of decomposition scored by TBS can be explained by the ADD. Furthermore, this new calculation derived from the original data set produces better prediction with better accuracy because of several statistical errors and limitations in Megyesi et al's research (10). The importance of temperature in estimating the time of death must be understood because each region has its characteristic temperature and humidity. A forensic doctor should be able to analyze and develop his/her method to estimate post-mortem interval following his/her local region (microclimate). The word microclimate refers to the specific climates condition in a smaller region that differs from the surrounding environment. The distinct condition of each region develops a different rate of decomposition, therefore, affecting the post-mortem interval (11). The ADD method can be implemented in Indonesia for estimating the post mortem interval

Table I: Total Body Score (TBS) Scoring System (8)

HEAD AND NECK		Score
Fresh stage	Fresh, no discoloration – slight lividity (pink/red)	1
Early decomposition stage	Insect activity; pronounced lividity (dark pink/red)	2
	Dark-red discoloration with some flesh still relatively fresh; edema of ears; maggots colonization (mouth); initial bloating of neck & skin slippage	3
	Discoloration &/or brownish shades particularly at edges, drying of nose, ears, & lips; prominent bloating of neck; maggot colonization (mouth, eyes, nose); purging of decomposition fluids (mouth)	4
	Purging of decomposition fluids (mouth, eyes, nose); brown discoloration; hair loss & skin slippage; the drying of lips, nose & ears	5
	Black discoloration of flesh; extensive maggot colonization & migration	6
Advanced decomposition stage	Caving in of the flesh & tissues of eyes & throat	7
	Moist decomposition with bone exposure of less than one half of the area being scored	8
	Mummification with bone exposure less than one half of the area being scored	9
Skeletonization	Bone exposure of more than half of the area being scored with greasy substances & decomposed tissue	10
	Bone exposure of more than half of the area being scored with desiccation of mummified tissue	11
	Bones are largely dry, but retaining some grease	12
	Dry bone	13
TRUNK		**Score**
Fresh stage	Fresh, no discoloration – slight lividity (pink/red)	1
Early decomposition stage	Skin appears shiny/glossy with early bloating & may show purple-black discoloration over the abdominal area	2
	Grey-purple to green discoloration; some flesh still relatively fresh; marbling of abdomen with maximum bloat	3
	Purple-black discoloration & purging of decomposition fluid; skin slippage with maggot-filled blisters present; hair loss	4
	Post the bloating following release of the abdominal gases, with extensive skin slippage & drying out of the skin	5
Advanced decomposition stage	Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity	6
	Moist decomposition with bone exposure of less than one half of the area being scored	7
	Mummification with bone exposure less than one half of the area being scored	8
Skeletonization	Bones with decomposed tissue, sometimes with body fluids & grease still present	9
	Bones with desiccated or mummified tissue covering less than one half of the area being scored	10
	Bones are largely dry, but retaining some grease	11
	Dry bone	12
EXTREMITIES		**Score**
Fresh stage	Fresh, no discoloration – slight lividity (pink/red)	1
Early decomposition stage	Pink-white appearance with bloating of proximal parts of limbs	2
	Grey-green discoloration; marbling & shiny appearance of skin; some flesh still relatively fresh; skin slippage & hair loss	3
	Discoloration &/or brownish shades particularly at edges, drying of the skin (starting distal to proximal)	4
	Brown to black discoloration, skin having a leathery appearance	5
Advanced decomposition stage	Moist decomposition with bone exposure of less than one half of the area being scored	6
	Mummification with bone exposure less than one half of the area being scored	7
Skeletonization	Bone exposure over one half of the area being scored, some decomposed tissue & body fluid remaining	8
	Bones are largely dry, but retaining some grease	9
	Dry bone	10

because the overall temperature, humidity, and the speed of wind throughout the day is being recorded by the Meteorology, Climatology, and Geophysical Agency in daily basis.

The ADD method has also developed in forensic entomology where the development of insect colonization on the body is also influenced by temperature. Therefore, the estimation of post-mortem interval using insect species and their life cycle has been developed further using the quantitative method of ADD. Some literature also reported that post-mortem estimation using ADD combined with an entomological approach yield a more accurate estimate compared to qualitative post-mortem changes (12). Another report also validates the usefulness of ADD method by applying it directly to actual murder cases. The post mortem estimation is compared to the perpetrator's testimony and showed a slight difference from the actual time when the murder happened. In the case of advanced decomposition, ADD method can be used to obtain useful post mortem interval estimation for solving the case (13).

The example of ADD method can be seen in the case report from Kim YS et al. They found a decomposed female body on June 27, 2017 around 13:00 near the road. No signs of injury and the body already covered

by maggots. The TBS were 7 points for the head, 2 points for the torso, and 3 points for the extremities, in the total of 12 points. Using the equation between TBS and ADD, they obtained the ADD value is 131.8 ~ 132 (Table II). The daily cumulative temperature from the date of discovery then examined and calculated from the Meteorological Agency data (13).

Date	6/21	6/22	6/23	6/24	6/25	6/26	6/27	6/28
Tempt (°C)	23.1	22.9	23.8	22.4	21.6	21.4	23.4	23.9

The estimation of post mortem interval using ADD was calculated backward from the date of discovery as follow:

1. Date 6/27: 19 hrs (field time) x 23.4°C (average temperature) ÷ 24 h = 18.525°C
2. Date 6/22 ~ 6/26: total ADD = 112.1
3. ADD from 6/22 ~ 6/27 : 112.1 + 18.525 = 130.625
4. Date 6/21: Remaining ADD is 132 - 130.625 = 1.375
5. Calculate the degree of the day from the remaining ADD: 1.375 x 24 = 33
6. Calculate the elapsed hour of the day from the remaining degree : 33 ÷ 23.1 = 1.428 hrs
7. 24 hrs - 1.428 hrs = 22.572 hrs; Therefore the PMI is on June 21, 23:00.

Implementation of ADD method also has been reported for drowning cases by Matues M et al. Six bodies were found drowned in the sea after the ship was accidentally swept away by the wave. The bodies were retrieved on different days between 7 and 11 days after the accident took place. Because decomposition is highly affected by temperature, meanwhile the temperature varies significantly between regions; the post mortem changes can't be used as an indicator for post mortem submersion interval. Thus ADD is best suited to use as it calculates the accumulation of thermal units over time. The ADD in these drowned cases was calculated from the sea surface temperature. The estimated ADD for the body resurfaced in bloating stage of decomposition lies between 100-1400C and the post mortem submersion interval depend on the ambient temperature, shorter for warmer water, and longer for cooler water. The estimated ADD for body resurfacing can be used as a clue for the search effort for missing drowning victims (14).

Because the Megyesi et al. and Moffat et al equation for determining the decomposition score is quantitative, it was thought that ADD method would meet the Daubert Standard and should be widely employed in PMI studies all around the world. However, human decomposition is not a linear process; hence a linear equation is insufficient. Due to the intricacy of the complete human decomposition process, which includes individual variability as well as internal and external variables that occur during the process, developing a suitable and accurate equation has been a challenging task. The more rudimentary way of looking at daily temperatures connected with gross observation of the body will continue to be necessary until a truly quantifiable method is established (15).

Table II: The Accumulated Degree Days Estimates (°C) and its interval for each calculated Total Body Score (10)

TBS_{Surf}	*ADD Estimate*	*Confidence Interval of the Limit*		
		50%	*75%*	*95%*
0	49	38 - 64	31 - 77	21 - 108
1	50	39 - 65	32 - 78	21 - 110
2	52	40 - 67	33 - 81	22 - 114
3	55	42 - 71	35 - 85	23 - 120
4	59	45 - 75	37 - 91	25 - 127
5	63	49 - 81	40 - 97	27 - 137
6	68	53 - 88	43 - 105	30 - 148
7	75	58 - 96	48 - 115	33 - 162
8	83	64 - 106	53 - 127	36 - 179
9	92	71 - 118	59 - 141	41 - 199
10	103	80 - 132	66 - 158	46 - 223
11	116	90 - 149	75 - 179	52 - 252
12	132	103 - 169	85 - 203	59 - 287
13	151	118 - 193	98 - 232	68 - 329
14	174	135 - 222	113 - 267	79 - 380
15	201	157 - 258	130 - 310	92 - 442
16	234	183 - 300	152 - 362	107 - 518
17	274	214 - 352	178 - 425	126 - 611
18	323	252 - 416	210 - 502	149 - 726
19	383	298 - 494	249 - 598	177 - 870
20	456	355 - 589	296 - 716	210 - 1048
21	546	424 - 708	353 - 862	252 - 1273
22	657	509 - 855	424 - 1045	302 - 1556
23	795	615 - 1039	511 - 1275	364 - 1916
24	967	745 - 1269	618 - 1564	440 - 2374
25	1182	907 - 1559	752 - 1930	534 - 2963
26	1452	1110 - 1926	917 - 2396	649 - 3723
27	1792	1363 - 2391	1123 - 2992	793 - 4710
28	2222	1681 - 2985	1381 - 3758	971 - 5998
29	2768	2082 - 3746	1705 - 4746	1193 - 7688
30	3464	2589 - 4725	2112 - 6027	1470 - 9919
31	4355	3233 - 5991	2626 - 7697	1816 - 12880
32	5500	4053 - 7633	3277 - 9883	2251 - 16830

TBS_{Surf} > 25 values are less reliable as they are beyond the extent of the data used in the model.
TBS_{Surf} = 0 is equivalent to TBS = 3 on Megyesi et al.'s scale.

CONCLUSION

Estimation of post-mortem interval is an integral part of medicolegal death investigation. Nonetheless, it becomes more difficult to estimate as the post-mortem changes advance. There is a need for a certain method that estimates the post-mortem interval accurately and reliably when decomposition has occurred. This ADD method takes into account temperature and time units to estimate the post-mortem interval as the major factor affecting the rate and process of decomposition is temperature. The ADD method has shifted the

estimation of post-mortem interval from the previous qualitative approach into a quantitative one, enabling a more complex analysis that can be scientifically justified in court.

ACKNOWLEDGEMENT

This study was supported by Research Grant 2018 (B-031/F12/KEPK/TL00/12/2019) from Center of Research and Publishing, Syarif Hidayatullah Jakarta State Islamic University.

REFERENCES

1. Indonesia Law of Health Number 36 the year 2009. Article 117 and 118. Promulgated on October 13th, 2009. State Gazette of the Republic of Indonesia year 2009 number 144. Jakarta.
2. Franceschetti L, Pradelli J, Tuccia F, Giordani G, Cattaneo C, Vanin S. Comparison of accumulated degree-days and entomological approaches in post-mortem interval estimation. Insects. 2021; 12: 264. https://doi.org/ 10.3390/insects12030264.
3. Bishop CP. Estimating postmortem interval: A molecular approach [Internet]. National Institute of Justice; 2014, June [cited 2022 April 25]. Available from: https://nij.ojp.gov/library/publications/estimating-postmortem-interval-molecular-approach.
4. Shrestha R, Kanchan T, Krishan K. Methods of Estimation of Time Since Death. National Library of Medicine. 2022, May [cited 2022 August 21]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK549867/
5. Gelderman HT, Boer L, Naujocks T, IJzermans ACM, Duijst WLJM. The development of a post-mortem interval estimation for human remains found on land in the Netherlands. Int J Legal Med. 2018; 132: 863-873.
6. Costa JO, Mello-Patiu CA. Application of forensic entomology to estimate the postmortem interval (PMI) in homicide investigations by the Rio de Janeiro Police Department in Brazil. Aggrawal´s Internet Journal of Forensic Medicine and Toxicology. 2004; 5(1): 40-44.
7. Myburgh J, L'Abbé EN, Steyn M, Becker PJ. Estimating the postmortem interval (PMI) using accumulated degree-days (ADD) in a temperate region of South Africa. Forensic Science International. 2013, June, 10; 229 (1–3): 165.e1-165.e6. https://doi.org/10.1016/j.forsciint.2013.03.037.
8. Megyesi MS, Nawrocki SP, Haskell NH. Using accumulated degree-days to estimate the postmortem interval from decomposed human remains. J Forensic Sci. 2005, May; 50(3): 618-26.
9. Michaud JP, Moreau G. A Statistical approach based on accumulated degree-days to predict decomposition-related processes in forensic studies. J Forensic Sci. 2011, January; 56, No. 1. DOI: 10.1111/j.1556-4029.2010.01559.x
10. Moffatt C, Simmons T, Lynch-Aird J. An improved equation for TBS and ADD: Establishing a reliable postmortem interval framework for casework and experimental studies. J Forensic Sci. 2016, January; Vol. 61, No. S1. DOI: 10.1111/1556-4029.12931.
11. Marhoff S, Fahey P, Green H. Estimating post-mortem interval using accumulated degree-days and a degree of decomposition index in Australia: A validation study. Australian Journal of Forensic Sciences. 2005, April; 48(1): 1-13. DOI:10.1080/00450618.2015.1021378.
12. Bala M, Sharma A. Postmortem interval estimation of mummified body using accumulated degree hours (ADH) method: A case study from Punjab (India). J Forensic Sci & Criminal Inves. 2016, March; 1(1): 555552.
13. Kim YS, Kim JH, Yoon KS, Kweon BS, Kim YS, Lee GY, et al. Feasibility of total body score (TBS) and accumulated degree days (ADD) in the estimation of postmortem interval for forensic murder casework. Biomed Sci Letters. 2018, March 31; 24: 35-42. DOI: https://doi.org/10.15616/BSL.2018.24.1.35.
14. Mateus M, Vieira V. Study on the postmortem submersion interval and accumulated degree days for a multiple drowning accident. Forensic Science International. 2014; 238: e15-e19. http://dx.doi.org/10.1016/j.forsciint.2014.02.026.
15. Bytheway JA, Steadman D, Wescott D. Validation Study of the Utility of Using Total Body Score and Accumulated Degree Days to Determine the Post-Mortem Interval of Human Remains from Three Human Decomposition Research Facilities. National Institute of Justice; 2018, June [cited 2022 April 25]. Available from: https://nij.ojp.gov/library/publications/validation-study-utility-using-total-body-score-and-accumulated-degree-days.