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# Evaluating the utility of time-lapse imaging in the estimation of post-mortem interval: An Australian case study

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ABSTRACT

Estimating post-mortem interval is an important aspect in forensic investigations. The aim of this study was to investigate if time-lapse imaging can be used to improve estimates of post-mortem interval using Megyesi et al.'s [1] method for a human donor decomposing in an Australian environment. To achieve this, time-lapse images were taken every 30 min over a 6-month period. The Megyesi et al. [1] total body score (TBS) system was used to quantify the level of decomposition of the donor for each image. Linear regression was performed to determine if observing decomposition more than once a day leads to increased accuracy in predicting PMI (post-mortem interval).

Decomposition initially progressed quickly and then plateaued at 1004 hours PMI, with a TBS of 24. Individual timestamps were created from the time-lapse images taken each day at 08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs, and 17:00 hrs. All timestamps produced $R^2$ values > 0.80, indicating that the Megyesi et al. [1] method accurately predicts PMI for this donor. The 08:00 hrs timestamp had the highest value $R^2 = 0.886$, whilst the combined timestamp (which included the scores from all five images for each 24-hour period) $R^2 = 0.823$ was the lowest.

This study supports the validity of Megyesi et al.'s [1] TBS model to estimate PMI. Two other interesting findings were that the results suggest that scoring TBS multiple times per day does not improve estimates of PMI, however scoring TBS at daybreak produces more accurate results than scoring TBS later in the day. This may be an important consideration in forensic scenarios.



## 1. Introduction

Estimating post-mortem interval (PMI), or the time since death, is an important aspect in forensic investigations. Police routinely call on forensic anthropologists and pathologists to estimate PMI in death investigations, regardless of the cause [2]. For unidentified remains, PMI estimates are entered into databases and compared to dates when people went missing to narrow down searches of missing persons' lists [3]. This helps police identify victims of homicide and fatal accidents, which is vital to ensure the rights of the deceased and those who survive them, including being able to return remains to loved ones.

Published formulas used to estimate PMI are based on experimental studies where human donor decomposition has commonly been scored in person by a researcher once a week, or at most once a day [4,5]. However, significant changes in decomposition may occur between observations, resulting in the introduction of errors into PMI formulas. In addition, decomposition studies conducted in different parts of the world have not been able to find a universal PMI formula, highlighting the importance of factoring in local environmental conditions [2], and the need for environment-specific data. Megyesi et al.'s [1] method has been tested in Australia with pigs but not humans. For example, Marhoff et al.'s [5] study found that Megyesi et al.'s [1] method was not accurate to measure the decomposition in pigs. The study presented here is the first to evaluate Megyesi et al.'s [1] method in human decomposition in the Australian environment.

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Time-lapse imaging allows greater frequency of scoring decomposition but has not previously been attempted in human taphonomic studies. Not taking advantage of time-lapse imaging results in less precise PMI estimates, thereby potentially negatively affecting death investigations. As a result, an experimental study was carried out, the aim of which was to address the research question: Can the use of time-lapse imaging improve estimates of post-mortem interval for a human donor decomposing in an Australian environment using Megyesi et al.'s [1] method?

## 2. Materials and methods

The sample population for this study consisted of one human body, donated to the Australian Facility for Taphonomic Experimental Research (shortened to AFTER), a research facility located in natural bushland in the Hawkesbury region of New South Wales. The donor was a mature male who died of natural causes. There were minor scrape-type injuries on the donor's legs, but no major penetrating or other injures present that would affect the time-death interval estimation.

Within 24 hours of death, the donor was placed outdoors at AFTER in a supine position on top of unaltered soil on the ground inside a cage 4.35 metres high, by 2.40 metres wide, 4.35 metres long. The cage had a door, which allowed researchers full access to all sides of the donor without having to disturb the body once it was *in situ,* to minimise potential external effects on decomposition (see Fig. 1); a cage is required to prevent scavengers from disturbing the remains and removing hard tissue elements. The donor was placed *in situ* in February 2018, and image capture was initiated within 2 hours of the donor arriving on site.

The cage was 4.35 m high, 2.4 m wide, and 4.35 m long. The donor was placed with his head 0.45 m from the top of the cage, and his right shoulder 0.66 m from the side of the cage.

Digital images were taken using five Brinno TLC 200 Pro time-lapse cameras, which have a resolution of 1.3 mega-pixels. All five cameras were fixed into position using support rods above the face 0.53 m from the ground surface, the left hand 0.44 m from the ground surface, the right hand 0.53 m from the ground surface, as well as a full top view 2.2 m from the ground surface, and a profile view of the entire body 0.25 cm from the ground surface (see Fig. 1). Recording was briefly stopped for approximately 1 to 2 minutes once a month to change the camera batteries and download images from the STD memory card to a secure laptop. Due to ethical restrictions, it is not possible to include images of the donor.

This study provided visual assessment of decomposition of the donor utilizing time-lapse images taken between February 2018 and August 2018. The camera positioned to provide a full top view of the entire body (see Fig. 1) provided the best images to score the decomposition in all three categories using Megyesi et al.'s [1] method (Table 1) and was therefore used as the data source for this study. Photographs were taken every 30 min during daylight hours for the first six months of decomposition. This is recognised as a limitation of this study, as it was not possible to observe changes that took place over night.

From the daylight images five pictures, one by each of the five cameras were taken at five individual time points 08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs, and 17:00 hrs, to assess decomposition rates in this study. The 08:00 hrs time was selected for inclusion in this study as it provided the clearest consistent view of the entire body for the first daylight image. The 3-hour interval timestamps, being 11:00 hrs, 14:00 hrs and 17:00 hrs were chosen for analysis to evenly divide the daylight hours and the 15:00 hrs timestamp was used as the standard 24-hour observation time as it is recorded as the hottest time of the day in Australia. The study used time-lapse images only to score decomposition, real-time observations were not conducted in person to score decomposition as the 15:00 hr s timestamp image was used as the standard 24-hour observation time. Photoscales were not included in the images for this study as they were not deemed necessary to address the research question.

### 2.1. Total body score and accumulated degree-days

This study used Megyesi et al.'s [1] quantitative method of estimating PMI using a total body score (TBS) system and accumulated degree-days (ADD). Therefore, in this study ADD was used instead of accumulated degree-hours (ADH) as it followed Megyesi et al.'s [1] method which used ADD, in order to test the method in Australia. TBS involves ranking observations of decomposition using a point-based system scoring three independent parts of the body; the head, torso, and limbs (Table 1). These scores are added together to produce a total body score. TBS values are then entered into the following equation: ADD = Log10/0.002*TBS*TBS+1.81 ± 388.16. The resultant value is the estimated number of accumulated degree-days needed for the donor to reach each stage of decomposition; where ADD = PMI (days) * temperature (°C).

In forensic cases where PMI is unknown, this model allows authorities to work backwards from the date of finding a body until the day the accumulated sum is reached to arrive at an estimated time since death. In experimental validation studies such as the present one, known PMI and estimated PMI can be compared to evaluate the accuracy of a model.

### 2.2. Statistical analysis

The timestamps above were evaluated in SPSS using linear regression to determine: 1) if the Megyesi et al. [1] model accurately predicted PMI for this donor; and 2) if observing decomposition more than once a day led to an increase in the precision of PMI estimation. Following Marhoff et al. [5] and Ceciliason et al. [6], $R^2$ values > 0.80 indicate accurate prediction of PMI.

TBS was scored for each image. These data were used to create a combined timestamp that included TBS scores from all five daily observations recorded at 08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs and 17:00 hrs. Five individual timestamps (08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs and 17:00 hrs) were also created that simulated standard observation studies by only utilizing observations performed once every 24 hours.

## 3. Results

### 3.1. Accumulated degree-days

To permit calculation of ADD, temperatures recorded hourly at AFTER over the first two months of decomposition were obtained from the University Technology Sydney (UTS). The temperature readings for the times at which TBS was scored – 08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs, and 17:00 hrs – were retained. PMI was calculated as the time elapsed between known time of death and the date and time at which TBS was scored. Comparison with climate statistics provided online by the Bureau of Meteorology for the Hawkesbury region from Richmond RAAF weather station, showed that daily maximum temperatures during the period under study (mean = 31.9° Celsius) were greater than the averages for the last 25 years (mean = 22.8° Celsius) [7]. This statistical difference in temperature (mean = 9.1° Celsius) would lead us to expect decomposition to proceed faster than normal.

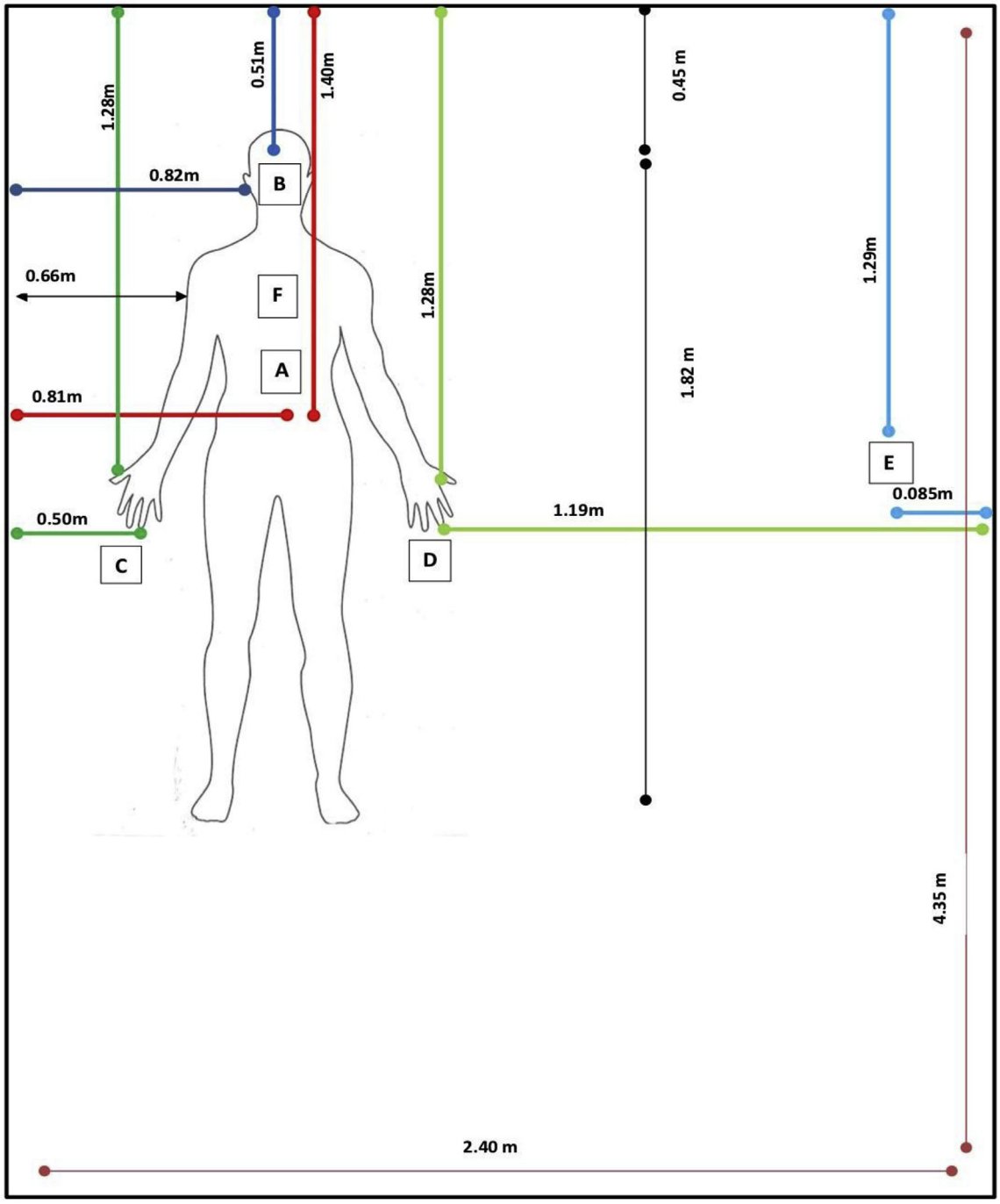


**Fig. 1.** Camera placements, cage dimensions and donor placement.
**Camera Placements**
A. Camera providing full top view of entire body = 2.2m from ground surface.
B. Camera above face = 0.53m from ground surface.
C. Camera above right hand = 0.53m from ground surface.
D. Camera above left hand = 0.44cm from ground surface.
E. Camera providing a profile view of body = 0.25cm from ground surface.
**Donor Placement**
F. Donor
Height of donor = 1.82m
Inside cage to head of donor = 0.45m Inside cage to Right shoulder of donor = 0.66m
**Cage Dimensions**
Height 4.35m x Width 2.40m x Length 4.35m Diagram not to scale.
m= metre

**Table 1**
Categories and Stages of Decomposition (from Megyesi et al. 2005).

| |
|---|
| Categories and stages of decomposition for the head and neck. |
| A. Fresh |
| - (1 pt) Fresh, no discoloration |
| B Early decomposition |
| - (2 pts) Pink-white appearance with skin slippage and some hair loss. |
| - (3 pts) Gray to green discoloration: some flesh still relatively fresh. |
| - (4 pts) Discoloration and/or brownish shades particularly at edges, drying of nose, ears and lips. |
| - (5 pts) Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present. |
| - (6 pts) Brown to black discoloration of flesh. |
| C. Advanced decomposition |
| - (7 pts) Caving in of the flesh and tissues of eyes and throat. |
| - (8 pts) Moist decomposition with bone exposure less than one half that of the area being scored. |
| - (9 pts) Mummification with bone exposure less than one half that of the area being scored. |
| D. Skeletonization |
| - (10 pts) Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue. |
| - (11 pts) Bone exposure of more than half the area being scored with desiccated or mummified tissue. |
| - (12 pts) Bones largely dry, but retaining some grease. |
| - (13 pts) Dry bone. |
| Categories and stages of decomposition for the torso |
| A. Fresh |
| - (1 pt) Fresh, no discoloration. |
| B. Early decomposition |
| - (2 pts) Pink-white appearance with skin slippage and marbling present. |
| - (3 pts) Gray to green discoloration: some flesh relatively fresh. |
| - (4 pts) Bloating with green discoloration and purging of decompositional fluids. |
| - (5 pts) Post-bloating following release of the abdominal gases, with discoloration changing from green to black. |
| C. Advanced decomposition |
| - (6 pts) Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity. |
| - (7 pts) Moist decomposition with bone exposure less than one half that of the area being scored. |
| - (8 pts) Mummification with bone exposure of less than one half that of the area being scored. |
| D. Skeletonization |
| - (9 pts) Bones with decomposed tissue, sometimes with body fluids and grease still present. |
| - (10 pts) Bones with desiccated or mummified tissue covering less than one half of the area being scored. |
| - (11 pts) Bones largely dry, but retaining some grease. |
| - (12 pts) Dry bone. |
| Categories and stages of decomposition for the limbs |
| A. Fresh |
| - (1 pt) Fresh, no discoloration |
| B. Early decomposition |
| - (2 pts) Pink-white appearance with skin slippage of hands and/or feet. |
| - (3 pts) Gray to green discoloration; marbling; some flesh still relatively fresh. |
| - (4 pts) Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities. |
| - (5 pts) Brown to black discoloration, skin having a leathery appearance. |
| C. Advanced decomposition |
| - (6 pts) Moist decomposition with bone exposure less than one half that of the area being scored. |
| - (7 pts) Mummification with bone exposure of less than one half that of the area being scored. |
| D. Skeletonization |
| - (8 pts) Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining. |
| - (9 pts) Bones largely dry, but retaining some grease. |
| - (10 pts) Dry bone. |
| Take each point value and sum them to find the total body score (TBS). |
| For example: 5 (head) + 5 (torso) + 5 (limbs) = 15 TBS |
| If an area of body has differential decomposition or different features (such as brown to black discoloration on relatively fresh skin on the torso) record both numbers. For the total body score, average the two numbers before totalling the body score. |
| Total body score is supposed to represent overall decomposition progression, so if you're unsure about where to fit a section of the body into a category either go for the lowest score or an average score. |

### 3.2. Total body score

TBS was plotted against PMI to determine the relationship between the known and estimated PMI using TBS (Fig. 2). The progression of decomposition was further demonstrated by plotting ADD against TBS (Fig. 3). The donor was in early decomposition upon initiation of image capture (approximately 2 hours after arriving at the research facility), measuring a TBS of six points using Megyesi et al.'s [1] method (Table 1). This score correlated closely with the donor's date of death in February 2018. The donor progressed naturally through early decomposition displaying grey to green discolouration, purging of decompositional fluids, and bloating along with post-bloating following release of abdominal gases, and black discolouration as per Megyesi et al.'s [1] model (Table 1). Fig. 2 shows how early decomposition progressed, moving to advanced decomposition when the TBS reached 19 at 434 hrs PMI. Advanced decomposition plateaued at 1004 hrs PMI with a TBS of 24. Fig. 3 shows that the donor was still in advanced decomposition with a TBS of 24 at the end of the 6-month study period and had not yet reached full skeletonization.

### 3.3. Linear regression analysis

TBS was plotted against Log10ADD (hourly temperature) for the combined timestamp (all observations at 08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs, and 17:00 hrs) of the 6-month study period in

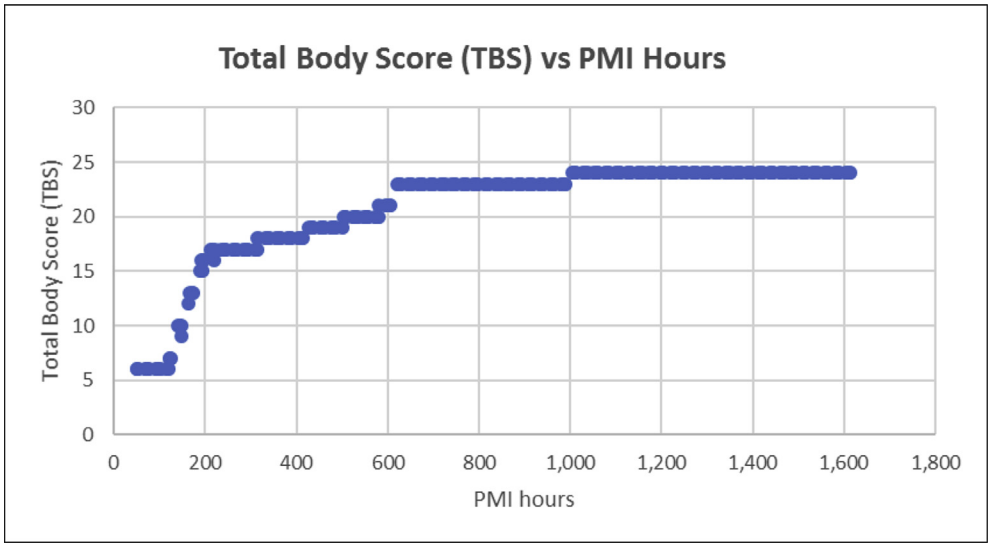


**Fig. 2.** Scatterplot comparing Total Body Score (TBS) to PMI Hours.

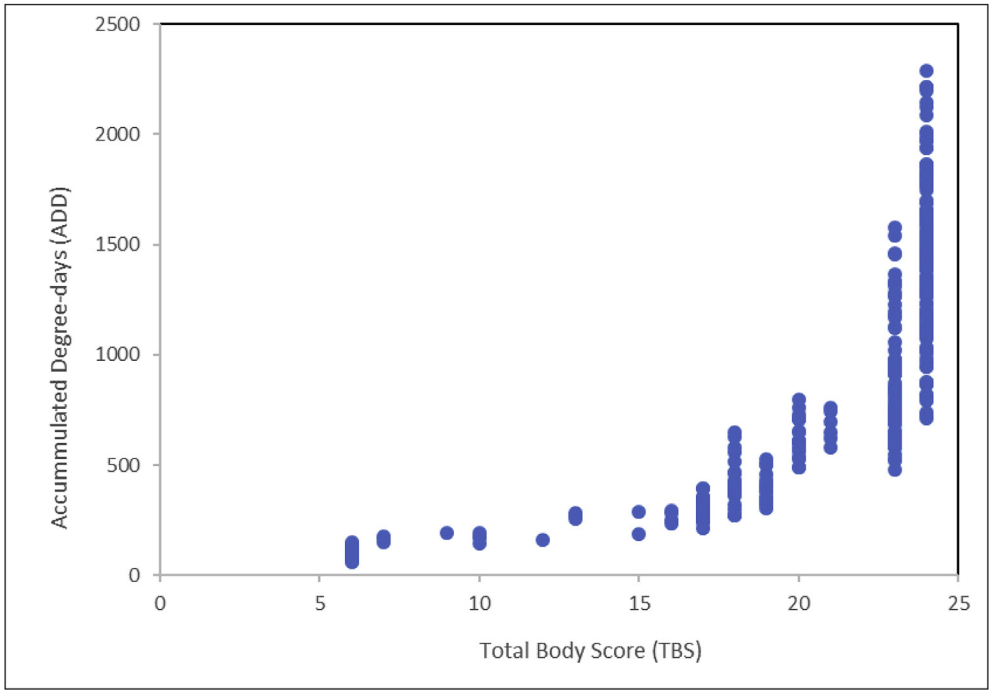


**Fig. 3.** Scatterplot comparing Accumulated Degree-days (ADD) to Total Body Score (TBS).

order to show the relationship between the decomposition TBS and ADD. Linear regression resulted in an $R^2$ value of 0.823 (Fig. 4). As this result was >0.80, this confirmed that using Megyesi et al.'s [1] model accurately predicted PMI for this donor under these specific environmental conditions. TBS was also plotted against Log10ADD for each individual timestamp which all resulted in $R^2$ values > 0.8 (Fig. 5).

The $R^2$ values of each timestamp were compared, which showed that the 08:00hr timestamp had the highest $R^2$ value of 0.886 (Fig. 5) indicating that measuring decomposition using Megyesi et al.'s [1] TBS system at this time of day yielded the most accurate results. However, the results did not show a benefit to scoring TBS multiple times a day due to the fact R square is highest for the 08:00 hrs timestamp $R^2 = 0.886$ (Fig. 5) and lowest for the combined timestamp $R^2 = 0.823$ (Fig. 4).

## 4. Discussion

This study investigated the utility of time-lapse imaging in the estimation of post-mortem interval for a human donor decomposing in an Australian environment. The human donor was monitored using Megyesi et al.'s [1] TBS system to score the stages of decomposition (Table 1) for each time-lapse image of the five combined timestamps (08:00 hrs, 11:00 hrs, 14:00 hrs, 15:00 hrs, and 17:00 hrs). The TBS and PMI were compared in a scatterplot (Fig. 2), which showed how early decomposition progressed quickly and then plateaued during advanced decomposition.

Marhoff et al. [5] and Ceciliason et al. [6] state that an R square

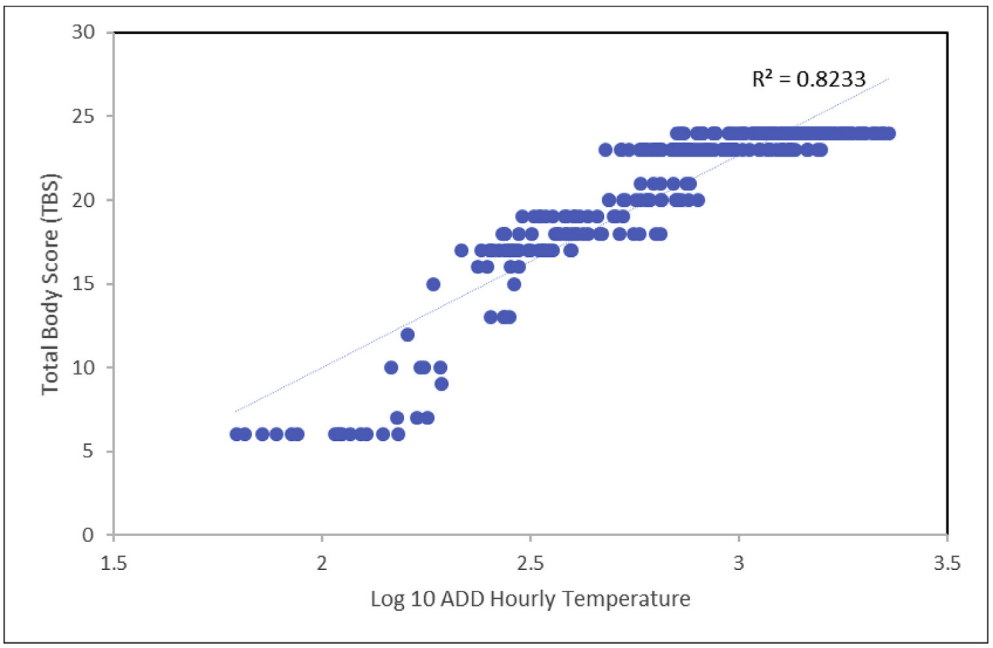


**Fig. 4.** Combined Timestamp – Total Body Score (TBS) compared to Log10ADD (Hourly Temperature).

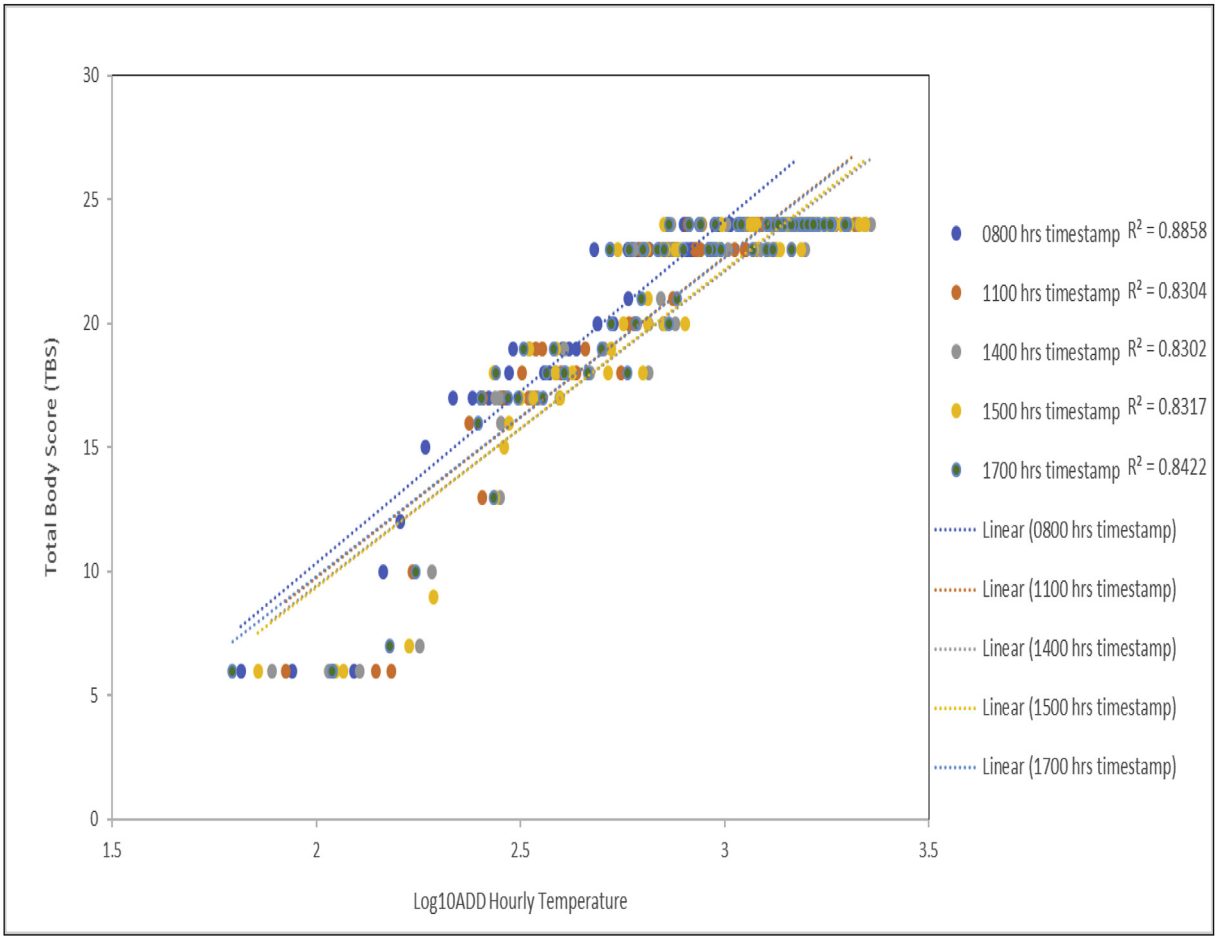


**Fig. 5.** Individual Timestamps (0800 hrs, 1100 hrs, 1400 hrs, 1500 hrs, 1700 hrs) - Total Body Score (TBS) compared to Log10ADD (Hourly Temperature) showing $R^2$ value.

value of >0.80 indicates the model accurately predicts PMI. Ceciliason et al.'s [6] study on human decomposition indoors did not fully support Megyesi et al.'s [1] model in an indoor setting. The linear regression resulted in similar $R^2$ values when plotting TBS against log10ADD or log10PMI indicating ADD does not improve estimate of PMI in Ceciliason et al.'s [6] data sample.

The human decomposition data collected in this study showed all the R squared values do reach this threshold with all data reaching >0.80 (Fig. 5), indicating that Megyesi et al.'s [1] model did accurately predict PMI in the Hawkesbury region for this donor under the given conditions; in particular when decomposition begins under hot summer temperatures (the donor was placed in February 2018). Cockle & Bell's [8] study used Vass's [9] formula to measure human decomposition, and the authors found that the results overestimated PMI when bodies were exposed to warmer temperatures. However in this study, the donor decomposed in Australian summer temperatures and all data returned results that support the Megyesi et al. [1] model. Therefore, this study supports the validity of Megyesi et al.'s [1] model for estimating PMI for bodies that have decomposed under summer Australian conditions.

Ribéreau-Gayon et al.'s [10] study on decomposition of pigs found using Megyesi et al.'s [1] method was significantly different when scoring TBS from photographs compared with those generated when the remains are scored *in situ* by a person. Both Marhoff and colleagues [5] and Ribéreau-Gayon et al. [10] found Megyesi et al.'s [1] model was not accurate when used to measure the decomposition of pigs, therefore suggesting that the model is more accurate in human decomposition as seen in this study.

If using Megyesi et al.'s [1] scoring method, this research demonstrated the best time of the day to measure decomposition was 08:00 hrs as it produced the highest R square value of 0.886 (Fig. 5). This result is an indication that decomposition increases during the night, although research is required to determine why this may be. In this study the R square value was highest for the 08:00hr timestamp ($R^2 = 0.886$ see Fig. 5) and lowest for the combined timestamp ($R^2 = 0.823$ see Fig. 4), suggesting there was no benefit to scoring TBS multiple times a day.

## 5. Conclusion

The estimation of PMI is of high importance in death investigations. Understanding decomposition rates for a human donor in the Australian environment is important for police, forensic anthropologists, and pathologists for the estimation of PMI to assist with the identification of unknown victims, as well as the investigation of criminal activity.

The application of Megyesi et al.'s [1] TBS method is supported by the results of this study, as it accurately predicted PMI for the donor in the Australian environment. Furthermore, the study demonstrated that scoring decomposition first thing in the morning (in this case 08:00 hrs) produced more accurate results than later in the day; a finding that has forensic relevance as, where possible, TBS should be estimated at this time of day to improve accuracy.

An expected outcome of this study was that scoring decomposition five times per day would be significantly more precise than standard observation studies in other research. This study did not result in more precise estimates than standard observational studies that capture data once every 24 hours.

These findings demonstrate that time-lapse imaging is an important source of documentation, and that it can be beneficial in scoring decomposition, in particular when using the Megyesi et al.'s [1] TBS system. This study was limited by the inability to assess TBS during hours of darkness, and results indicate that decomposition is accelerated at night. Future research should utilize night-vision technology to capture decomposition rates during darkness, with a view to establishing why they increase. The findings presented here begin to address the gap of factoring in local environment conditions when using a PMI formula, although more investigation is required.

## Declaration of competing interest

Authors declare there is no conflict of interest.

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In accordance to National Health and Medical Research Council (NHMRC) guidelines, this research was approved by the Human Research Ethics Committee (HREC) at Central Queensland University, University of Technology Sydney, and University of Newcastle.

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