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The suitability of visual taphonomic methods for digital photographs: An experimental approach with pig carcasses in a tropical climate

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ABSTRACT

In the context of increased scrutiny of the methods in forensic sciences, it is essential to ensure that the approaches used in forensic taphonomy to measure decomposition and estimate the postmortem interval are underpinned by robust evidence-based data. Digital photographs are an important source of documentation in forensic taphonomic investigations but the suitability of the current approaches for photographs, rather than real-time remains, is poorly studied which can undermine accurate forensic conclusions. The present study aimed to investigate the suitability of 2D colour digital photographs for evaluating decomposition of exposed human analogues (*Sus scrofa domesticus*) in a tropical savanna environment (Hawaii), using two published scoring methods; Megyesi et al., 2005 and Keough et al., 2017. It was found that there were significant differences between the real-time and photograph decomposition scores when the Megyesi et al. method was used. However, the Keough et al. method applied to photographs reflected real-time decomposition more closely and thus appears more suitable to evaluate pig decomposition from 2D photographs. The findings indicate that the type of scoring method used has a significant impact on the ability to accurately evaluate the decomposition of exposed pig carcasses from photographs. It was further identified that photographic taphonomic analysis can reach high inter-observer reproducibility. These novel findings are of significant importance for the forensic sciences as they highlight the potential for high quality photograph coverage to provide useful complementary information for the forensic taphonomic investigation. New recommendations to develop robust transparent approaches adapted to photographs in forensic taphonomy are suggested based on these findings.

1. Introduction

Accurate postmortem analysis and interpretation of human remains is crucial to forensic death investigations. In many forensic cases, human remains are subject to decomposition associated with extensive postmortem changes. Reaching postmortem conclusions, including the cause and manner of death, postmortem interval (PMI), and identification of the deceased, rely on the accurate interpretation of these changes (biophysicochemical characteristics) both at the death/decomposition scene and in laboratory [1–4]. This field of research and application is forensic taphonomy [5–7].

A number of methods were developed to evaluate and measure decomposition, including carbon dioxide release [7,8], gravesoil chemistry [9–11], RNA degradation [12–14], and mass loss [15–18]. Another approach [19] relies upon the appearance of gross postmortem changes, including to the hard and soft tissues, that are visually assessed and allocated a number (a score). This approach, commonly referred to as Total Body Score (TBS), has been used widely by forensic taphonomists because it possesses all of the traits of an ideal technique; it is readily available, cost-effective, rapid, and simple [20]. However, the reliability of TBS is influenced by a wide range of variables, including those linked with the methodology and the experimental conditions, that may undermine the accuracy of the postmortem conclusions [21–23]. It is thus very important that forensic taphonomy relies on evidence-based interpretations underpinned by robust methods [24–28].

Abbreviations: ADD, Accumulated Degree Day; ANOVA, Analysis of Variance; BDS, Body Decomposition Score; CI, Confidence Interval; FDS, Face Decomposition Score; HSD, Honest Significant Difference; ICC, Intra-class Correlation Coefficient; LDS, Limbs Decomposition Score; PMI, Postmortem Interval; SD, Standard Deviation; SE, Standard Error; TBS, Total Body Score

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Fig. 1. Decomposition of pig (*Sus scrofa domesticus*) carcasses in Palolo Valley, Oahu, Hawaii placed on stainless steel metal mesh (63.5 mm × 63.5 mm) and PVC frame to facilitate mass loss measurements throughout the duration of the experiment in Winter/Spring (February – April) after five hours postmortem when no visible changes could be observed (Fresh stage) (a). Bloating was observed by 30 h postmortem (Early decomposition) (b), with *rigor mortis* and widespread postmortem colour changes observed by 54 h postmortem (Early decomposition) (c). The abdomen of the black pig carcass ruptured by 54 h postmortem (Early decomposition) (d) and all carcasses supported numerous fly larvae (Early/Active decomposition) (e), which were observed from 30 h to approximately 10 days postmortem (252 ADD). Little mass loss (~7%) and gross postmortem change was observed after 11 days postmortem (279 ADD) (Advanced decomposition) (f).

The method developed by Megyesi et al. [19] after Galloway et al. [29] is a well-established approach to visually evaluate decomposition of human remains in a forensic context [30]. Although the method was developed from photographs, it is often applied in forensic reconstructions and empirical research for in situ remains, including non-human materials such as pigs, rabbits, and mice [31–37]. To the authors' knowledge, the suitability of the Megyesi et al. [19] method for these materials and contexts has not been validated yet. To date, it appears that only the study by Keough et al. [30] investigated the suitability of the Megyesi et al. method for exposed in situ pig remains and found significant differences between human and porcine decomposition processes in the early postmortem periods. Most forensic taphonomy studies focus on providing new data from various environments but there is a paucity of studies on the suitability of the available scoring methods for certain forensic contexts, including when photographs of the remains are used [22,23].

Specifically, there is a lack of research to test the suitability of taphonomic photography-based approaches in an experimental manner. However, photographs of the death/decomposition scene and the corpse itself are a standard documentation in forensic investigations [38–41] and can be the only available source of information when the actual remains are not accessible [19,29,42–46]. Because of this discrepancy between the knowledge base available and the current practice, the suitability of digital photographs to evaluate decomposition in lieu of the original remains is unclear, which can be problematic for forensic death investigation as any misevaluation of postmortem changes and PMI can hamper accurate forensic conclusions, including the positive identification of the deceased. Establishing the baseline for scoring decomposition from photographs is thus critical.

To address this gap in the knowledge, an experimental study was conducted to evaluate the applicability of two published taphonomic methods in pig remains (*Sus scrofa domesticus*), used as proxy for human corpses, under the following conditions: (i) in real-time and (ii) using digital colour photographs scored by observers. The aim of this study was not to validate the methods but to provide a baseline for scoring decomposition of exposed remains by evaluating the repeatability of decomposition body scores according to materials (carcass and photograph) and methods.

To achieve this objective, decomposition body scores were generated by two groups of observers, one based in the United States of America (USA), the other in the United Kingdom (UK). To meet the objective of setting a baseline for forensic taphonomy, this study attempted to be as close to real forensic cases conditions as possible, in which persons in charge of evaluating the decomposition stage of human corpses at death/decomposition scene (e.g. first responders and death investigators) can come from different backgrounds with various levels of education and experience in collecting evidence from dead bodies [45,47,48].

This research addresses two complementary questions: (i) Are the Megyesi et al. [19] and Keough et al. [30] methods suitable to evaluate pig decomposition from 2D colour digital photographs in lieu of real-time remains?; and (ii) are the decomposition body scores generated from the photographs consistent and reproducible between the two groups of observers? The research hypotheses considered here were

that (i) decomposition body scores generated in real-time will not differ from the scores generated using photographs, and (ii) photographic decomposition scores will not differ between observers.

2. Materials and methods

2.1. Carcasses and decomposition site

Pig carcasses (*Sus scrofa domesticus*) were chosen for this study as they are commonly used as analogues for human cadavers in forensic taphonomic experimental studies [18,37,49–54]. Three pig carcasses (*Sus scrofa domesticus*) were acquired from farms near Waianae, Oahu, Hawaii. Two carcasses were white/pink and one was black. Carcass mass was 38.8 kg, 54.6 kg, and 57.5 kg, respectively. No animals were killed for the purpose of this study and the carcasses were handled in accordance with The Institutional Animal Care and Use Committee policy on Animal Material (USA). The three pigs were killed using a bolt gun to the forehead. The carcasses were placed in plastic transport bags and driven to the decomposition site at ambient temperature (~25 °C) within 1 h after death. Upon arrival at the decomposition site, carcasses were removed from plastic transport bags and placed on a plastic and metal frame to facilitate the measurement of carcass mass (Fig. 1). All carcasses were placed on their left side on the frames, and spaced approximately seven meters from each other. The carcasses were left decomposing for fourteen days from 28th February to 14th March 2017 (with a check at 42 days postmortem on 11th April 2017) on the soil surface within a 900 m^2 outdoor taphonomy facility located in the Palolo Valley near Honolulu, Hawaii. This site is located on an east-facing slope, so that the carcasses were in the direct sun until mid-afternoon. The site is approximately 285 ft above sea level and is located in a tropical savanna climate [55] where mean annual precipitation is approximately 700 mm, 70% of which arrives in the Autumn and Winter (October to March). The soil at the site is rocky and covered with a vegetation representative of a tropical savanna ecosystem on Oahu with a dominance of sandbur (*Cenchrus echinatus*) and Guinea grass (*Megathyrsus maximus*) with night blooming cereus (*Hylocereus undatus*), aloe (*Aloe* cf. *massewana*), corpse flower (*Stapelia gigantea*), panda plant (*Kalanchoe tomentosa*), bellyache bush (*Jatropha gossypiifolia*), koa haole (*Leucaena leucocephala*), monkeypod (*Samanea saman*), sweet acacia (*Vachellia farnesiana*), spurflower (*Plectranthus parviflorus*), and bougainvillea (*Bougainvillea* sp.). Few scavengers were noticed at the decomposition site, with only the small Asian mongoose (*Herpestes javanicus*) observed [56].

2.2. Temperature and relative humidity

A portable datalogger (HOBO U23 Pro v2, Product #U23-001, Onset Corp., Cape Cod, MA, USA) was placed at the decomposition site to measure ambient temperature (°C) and relative humidity (%) at intervals of 1 h. The datalogger was placed on the soil surface out of direct sun and within 20 m of every carcass. These weather data enabled the calculation of accumulated degree days (ADD) for each carcass at every in situ observation [19]. ADD were calculated using 0 °C as the minimum developmental threshold [9].

2.3. Camera

Photographs were taken with a FujiFilm FinePix HS-20EXR fixed lens digital camera (Fujifilm Corporation, Edison, NJ, USA) with a Peca visible pass filter (Product #918, 58 mm, Peca Products, Inc., Beloit, WI, USA).

2.4. Carcass mass loss

To facilitate mass loss measurements, slings made from 3.8 cm diameter PVC pipe, galvanized steel chained-link fence, and 0.635 cm × 0.635 cm stainless steel mesh were used [57] (Fig. 1). Mass (in kilograms) was measured with an electronic hanging balance (American Weigh Scales, H-110, China) immediately after placement at the decomposition site (Fig. 1) [17,18]. This was achieved by lifting the frames off the ground for approximately 10 s to ensure minimum disturbance of the carcasses and the decomposition process. Mass was measured at 24 h intervals for 14 days and then checked again four weeks later at 42 days postmortem.

2.5. Decomposition body scores

Decomposition body scores were generated using two methods [19,30]. Megyesi et al. [19] developed a method for scoring the decomposition from 2D photographs of exposed human remains by examining a corpse as three body regions: Head and Neck, Trunk, and Limbs. Each body region is assigned a numerical score (body score) based on their physical macroscopic appearance. The body scores can be summed to calculate the Total Body Score (TBS) which can then be used to estimate PMI [19]. Building on this methodological and knowledge base, Keough et al. [30] developed a similar method to score real-time decomposition of pig remains.

2.6. Experimental protocol

Following carcass placement on the 28th February 2017, mass loss and decomposition scores were measured at 24 h intervals for the initial 14 days of decomposition as previous research at this site showed that very little decomposition takes place after ten to twelve days postmortem [56,57]. Carcasses were then monitored again at 42 days postmortem to look for any significant changes in the decomposition process. All carcasses were photographed at the time of placement and at every in situ observation thereafter. The carcasses were photographed in a standardised fashion to maximise the ability to capture taphonomic phenomena throughout the decomposition. Photographs from above were taken to capture the whole right side (Fig. 1a), and close-up photographs parallel to the soil surface were taken to capture details of the three body regions of interest (head/neck, trunk, and limbs) (Fig. 1c). When any interesting taphonomic phenomenon was noticed, such as insect activity, bloating, and colour changes, additional photographs were taken using the same standardised views and angles. Various numbers of photographs were thus available for each time point (Table 1).

In a first phase, three observers from the USA group, with less than one year experience scoring decomposition, evaluated the decomposition stage of the three pig carcasses in real-time, using the two methods described above [19,30], under the supervision of an experienced expert. Approximately four weeks following the end of the experimental decomposition, nine observers from the USA group were asked to evaluate the decomposition stage of the pig carcasses from photographs taken in the first phase of the study, using the same two methods [19,30]. The group consisted of Undergraduate students (n = 9) with 22.2% and 77.8% of males and females respectively, ranging from 22 to 46 years old with a median age of 25 (8.4 SD) (mean age = 28.8 [2.8 SE]; mode = 22).

In the second phase, a second group of observers (UK group) of comparable composition and size (n = 9) scored the same photographs to evaluate the reproducibility of the first results. The group consisted of Postgraduate students (Master n = 5; PhD n = 4) with 100% of females, ranging from 22 to 41 years old with a median age of 24 (5.9 SD) (mean age = 26.3 [2 SE]; mode = 23).

As part of this study, the eighteen observers were asked to evaluate the amount of decomposition they could see on the photographs provided, using the two aforementioned methods [19,30]. Fifty-one folders containing 2D digital colour photographs (ranging from two to six, with a mean and mode of four) of the three pig carcasses in various decomposition stages were provided along with the original published

Table 1
Photographic material provided to the observers to score decomposition, along with the corresponding pig carcasses and PMIs.

Photo folder	Pig carcass [a]	N photographs per folder	PMI (hours)
7	1	3	2.5
27	3	3	2.5
34	2	3	2.5
17	1	3	5.5
26	2	3	5.5
49	3	3	5.5
1	3	5	30
8	2	4	30
25	1	3	30
10	3	6	54
19	2	5	54
35	1	6	54
24	3	4	78
32	1	3	78
36	2	4	78
3	2	3	102
11	1	4	102
38	3	4	102
9	2	4	126
20	3	4	126
47	1	4	126
23	2	2	150
29	1	3	150
39	3	4	150
31	3	4	174
42	2	4	174
43	1	4	174
4	2	4	198
5	3	4	198
18	1	5	198
13	1	4	222
14	2	5	222
28	3	3	222
30	2	4	246
40	3	5	246
50	1	4	246
2	1	4	270
41	2	3	270
51	3	4	270
15	2	6	294
33	1	6	294
46	3	4	294
16	2	4	318
44	3	4	318
45	1	4	318
12	2	4	342
21	1	4	342
22	3	4	342
6	1	4	1014
37	2	3	1014
48	3	4	1014

[a] Pig 1: 54.6 kg with a pink/white skin tone; Pig 2: 57.5 kg with a black skin tone; Pig 3: 38.8 kg with a pink/white skin tone.

methods [22,23] (Table 1). The photographs were independently and blindly scored on conventional flat computer screens. The observers were also asked to report any photographs they found particularly helpful to score decomposition and leave any useful comments on their experience scoring the photographs. The observers were instructed to complete the scoring in their own time within a period of two weeks and they agreed not to research information on how to evaluate decomposition and how to apply the methods for the duration of their involvement in the study for it to be conducted in conditions close to that of real forensic scenarios. The written consent of the observers for their data to be collected and analysed was obtained. All the observers shared a background in forensic anthropology. The variables of the level of study, the experience of the observers using the two scoring methods, as well as their confidence levels in their decomposition scores were not collected in this study but they will be investigated in future studies. Once the data were collected, the accuracy of the sum of the three decomposition body scores to generate the TBS was verified. ≥ 1 error was found in thirteen observers (72.2%) and were automatically recalculated with Microsoft Excel for Mac version 15.32 prior to further analysis [22].

2.7. Statistical analyses

Descriptive and inferential statistics were generated using Prism 7.0a [58] for Mac OS X and SPSS v. 24.0 [59] for PC. First, inter-observer reliability was investigated by calculating inter-observer consistency and agreement. Inter-observer consistency provided information on the level of linear relationship between the observers, while the absolute agreement enabled to evaluate how close the observers were in terms of the decomposition scores they generated. Inter-observer consistency was calculated with a Cronbach's alpha and average inter-observer agreement was calculated with an intraclass correlation coefficient (ICC), using a two-way mixed model. Two-way Analysis of Variance (ANOVA) was then conducted to research any differences in the decomposition body scores generated in real-time and from photographs, as well as in photograph scores between the two groups of observers. *Post hoc* Tukey honest significant difference (HSD) tests were subsequently performed to investigate the effect of Observer Group and PMI on TBS. The TBS of each observer were compared with one another, producing a total of 36 comparisons. Spearman's correlation coefficient was used to quantify the degree to which carcass mass loss and TBS were related. A p value of < 0.05 was considered as significant.

3. Results

3.1. Gross carcass decomposition and mass loss

3.1.1. Patterns and rates of carcass decomposition

Carcasses were subject to temperature and relative humidity consistent with previous studies at this site [60] with daily average temperature ranging from 21.1 °C to 32.2 °C and a daily average relative humidity ranging from 57.5% to 100% (Fig. 2a). The carcasses also underwent postmortem changes similar to previous studies [60] in terms of extent, timing, and duration. No postmortem changes were observed during the initial 24 h postmortem, other than the presence of adult flies (e.g. *Lucilia sericata*, *Chrysomya rufifacies*) on and around the remains (Fig. 1a). Initial indications of bloating as well as fly egg masses and larvae were observed by 30 h postmortem (~29 ADD) (Fig. 1b). Clear postmortem colour changes were observed on Day 2 (45 ADD) (Fig. 1c). The black-skinned carcass presented an abdominal rupture by this time (Fig. 1d). Carcasses released great quantities of decomposition fluids (the so-called 'purging') and were colonised by fly larvae from Day 2 through Day 9 (228 ADD) (Fig. 1e). The majority of fly larvae migrated by Day 10 (252 ADD) when remains started to desiccate with little visible postmortem change.

3.1.2. Carcass mass loss and Total Body Score

Carcass mass loss and Total Body Score followed similar patterns. Little mass loss (< 1%) was observed until Day 3 (80 ADD) (Fig. 2b). No significant differences were found between the decomposition scores generated from the three carcasses, regardless of mass and skin tone ($F_{2, 45} = 0.789$, $p < 0.05$). Carcasses lost approximately 70% of their mass from Day 3 (80 ADD) to Day 10 (252 ADD), after which time mass loss proceeded slowly; carcasses lost 6% of their mass from Day 10 (252 ADD) to Day 42 (1211 ADD). TBS generated after Megyesi et al. [19] was significantly different than TBS generated after Keough et al. [30] ($F_{1, 8} = 70.8$, $p < 0.001$). Most of these differences were observed after Day 3 (80 ADD). All TBS followed a pattern similar to mass loss although a delay in the increase of TBS during the initial 72 h postmortem was not observed (Fig. 2c).

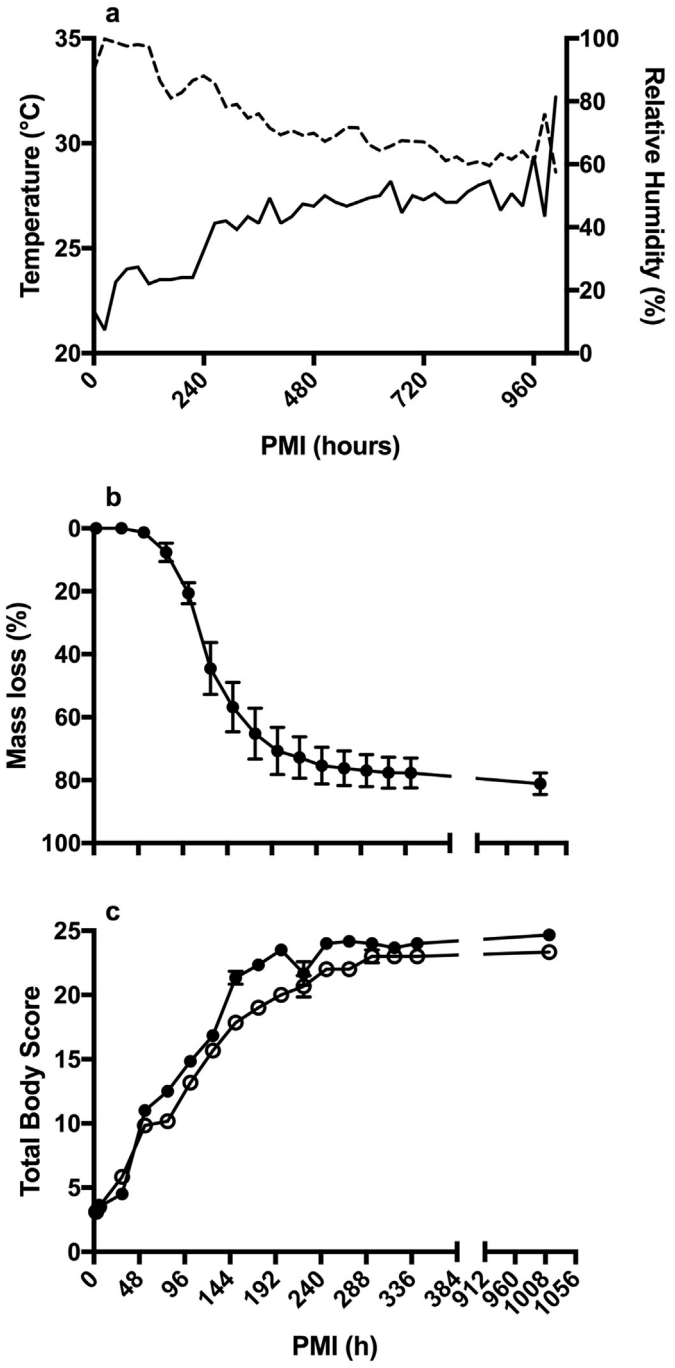

Fig. 2. Daily average temperature (–) and relative humidity (- -) during the decomposition of pig (*Sus scrofa domesticus*) carcasses in Palolo Valley, Oahu, Hawaii from 28th February 2017 to 11th April 2017 (a). Carcass mass loss (b) and Total Body Score (c) were measured in real-time at 24 h intervals beginning at six hours postmortem. Total Body Score (c) was measured using methods developed by Megyesi et al. [19] (●) and Keough et al. [30] (○). Bars represent standard error where $n = 3$.

3.2. Inter-observer reliability: consistency and agreement

3.2.1. Real-time: the USA group

A high inter-observer consistency was found across the TBS generated with the Megyesi et al. [19] and Keough et al. [30] methods ($\alpha = 0.997$ for both methods). 'Almost perfect agreement' was reached across the TBS generated from the real-time carcasses with the Megyesi et al. [19] and Keough et al. [30] methods (ICC = 0.997 for both methods) [61] (Table 2). The Limbs decomposition scores were the least concordant amongst the observers with the Megyesi et al. [19] method, while the Trunk scores were the least concordant with Keough et al. method [30] (Table 2).

Table 2
Inter-observer reliability of the real-time and photograph decomposition body scores generated using Megyesi et al. [19] and Keough et al. [30] methods, by group of observers (USA and UK).

	Inter-observer consistency (Cronbach's alpha)	95% confidence interval	Inter-observer absolute agreement (ICC)	95% confidence interval
Megyesi et al. [19]				
USA Real-time				
Head/Neck	0.993	0.988–0.996	0.993	0.988–0.996
Trunk	0.994	0.991–0.997	0.995	0.991–0.997
Limbs	0.991	0.986–0.994	0.991	0.986–0.994
TBS	0.997	0.996–0.998	0.997	0.996–0.998
USA photographs				
Head/Neck	0.861	0.807–0.908	0.824	0.745–0.886
Trunk	0.856	0.801–0.904	0.825	0.751–0.886
Limbs	0.818	0.751–0.877	0.778	0.689–0.852
TBS	0.870	0.819–0.914	0.834	0.757–0.893
UK photographs				
Head/Neck	0.869	0.818–0.913	0.843	0.776–0.898
Trunk	0.885	0.839–0.924	0.848	0.773–0.988
Limbs	0.827	0.763–0.884	0.740	0.611–0.836
TBS	0.902	0.862–0.936	0.858	0.780–0.913
Keough et al. [30]				
USA Real-time				
Head/Neck	0.993	0.988–0.996	0.993	0.988–0.996
Trunk	0.991	0.986–0.994	0.991	0.986–0.994
Limbs	0.994	0.991–0.997	0.995	0.991–0.997
TBS	0.997	0.996–0.998	0.997	0.996–0.998
USA photographs				
Head/Neck	0.864	0.811–0.910	0.822	0.739–0.986
Trunk	0.851	0.794–0.900	0.816	0.738–0.880
Limbs	0.831	0.768–0.887	0.780	0.683–0.857
TBS	0.873	0.823–0.916	0.831	0.749–0.892
UK photographs				
Head/Neck	0.867	0.815–0.912	0.827	0.746–0.889
Trunk	0.898	0.856–0.933	0.863	0.794–0.914
Limbs	0.849	0.791–0.899	0.771	0.652–0.857
TBS	0.913	0.876–0.943	0.869	0.793–0.921

3.2.2. Photographs: the USA group

A high inter-observer consistency was found across the TBS generated with the Megyesi et al. [19] and Keough et al. [30] methods ($\alpha = 0.870$ for both methods). 'Almost perfect agreement' was reached across the TBS generated from the photographs of the carcasses with the Megyesi et al. [19] and Keough et al. [30] methods (ICC = 0.834, for both methods) (Table 2). The Limbs decomposition scores were the least concordant, with both methods. With the Keough et al. method [30], the Head/Neck scores were the most concordant (Table 2).

3.2.3. Photographs: the UK group

A high inter-observer consistency was found across the TBS generated with the Megyesi et al. [19] and Keough et al. [30] methods ($\alpha = 0.902$ and 0.913, respectively). 'Almost perfect agreement' was reached across the TBS generated from the photographs of the carcasses with the Megyesi et al. [19] and Keough et al. [30] methods (ICC = 0.858 and 0.869, respectively) (Table 2). The Limbs decomposition scores were the least concordant while the Trunk scores were the most concordant, with both methods (Table 2).

3.2.4. Photographs: the USA and UK groups

In both groups, there were no distinct differences in the TBS generated according to the numbers of photographs available as high inter-observer reliability rates were reached (> 0.81) [61], regardless of the method used. Only one folder contained two photographs and as such,

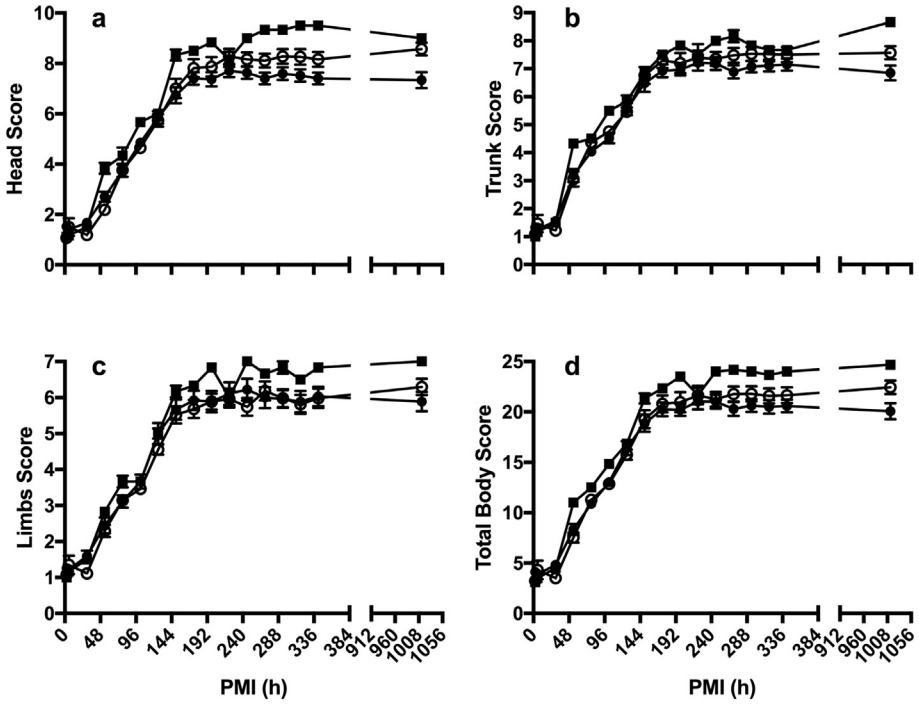

Fig. 3. Decomposition body scores of pig (*Sus scrofa domesticus*) carcasses in Palolo Valley, Oahu, Hawaii using the scoring method developed by Megyesi et al. [19]. Decomposition body scores were generated by carcass region including Head and Neck (a), Trunk (b), and Limbs (c). These scores were them summed to generate a Total Body Score at each PMI (d). Decomposition body cores were generated in real-time (■) and using 2D digital colour photographs. Photograph decomposition scores were generated by observers in the USA (○) and the UK (●) (*n* observers in each group = 9). Bars represent standard error where $n = 9$.

the inter-observer reliability could not be compared to that of the other photo folders. The folders containing four photographs and scored with the Megyesi et al. [19] method showed a slightly lower inter-observer reliability rate as the other folders (> 0.69). This could be explained by the fact that folders with four photographs were the most frequent in the material provided to the observers. Also, no distinct differences in the TBS generated from the three pig carcasses were found, as high inter-observer reliability rates were reached (> 0.78) [61], regardless of the method used.

3.3. Real-time versus photographs: the USA group

Real-time TBS and body scores generated using the Megyesi et al. [19] method were consistently significantly different than photograph scores ($F_{1, 34} = 8.48$, $p < 0.05$). This effect varied by postmortem interval (PMI) (a phenomenon that is referred to here as the 'PMI effect') where photograph scores were consistently greater than real-time scores before 30 h postmortem but were then consistently less than real-time scores from 30 h postmortem until the end of the experiment at 1008 h postmortem ($F_{16, 544} = 183$, $p < 0.05$) (Figs. 3 and 4a). Conversely, real-time TBS and body scores generated using the Keough et al. method [30] were not significantly different from photograph scores ($F_{1, 34} = 0.101$, $p > 0.05$). A similar significant impact of PMI on TBS was however observed where photograph scores were consistently greater than real-time scores before 30 h postmortem but were then consistently less than real-time scores until the end of the experiment at 42 days postmortem ($F_{16, 544} = 172$, $p < 0.05$) (Fig. 5).

3.4. Real-time versus photographs: the UK group

Real-time TBS and Head/Neck, and Trunk decomposition scores generated using Megyesi et al. method [19] were consistently significantly different than photograph scores ($F_{1, 34} = 13.3$, $p < 0.05$). However, no significant difference was observed in the Limbs decomposition scores ($F_{1, 34} = 2.76$, $p > 0.05$). This effect varied by PMI where photograph scores were consistently greater than real-time scores before 54 h postmortem but were then consistently less than real-time scores until the end of the experiment at 1008 h postmortem ($F_{16, 544} = 215$, $p < 0.05$) (Figs. 3 and 4b). Conversely, real-time TBS and body scores generated using Keough et al. method [30] were not significantly different from photograph scores ($F_{1, 34} = 2.63$, $p > 0.05$), with the exception of the Head/Neck decomposition scores ($F_{1, 34} = 6.2$, $p < 0.05$). No consistent PMI effect was observed ($F_{16, 544} = 213$, $p > 0.05$) (Fig. 5).

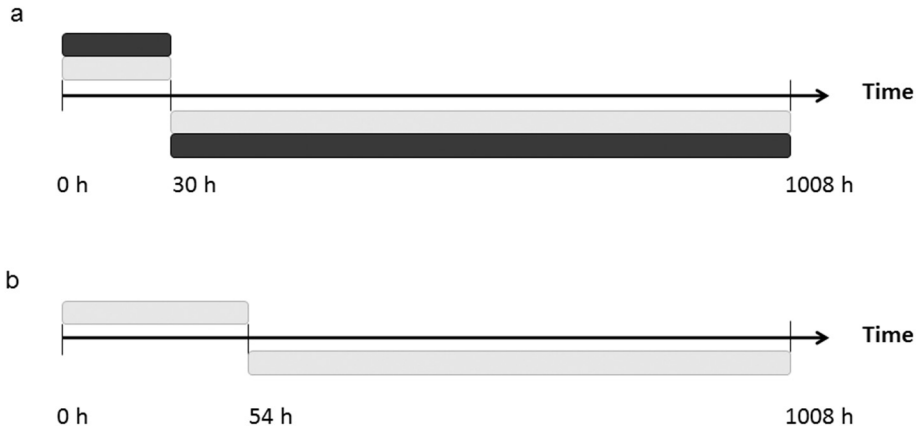

Fig. 4. Misestimation of photograph TBS throughout time according to the methods used (Megyesi et al. [19], in light grey, and Keough et al. [30], in darker grey) between groups of observers. Only photograph TBS that significantly differed from real-time TBS are shown (similarities are not shown). The USA group (a) showed constant overestimation of photograph TBS in the early postmortem periods (until 30 h) and then constant underestimation up to the end of the experiment at 1008 h, regardless of the method used. A similar pattern was observed in the UK group (b) with constant overestimation of the photograph TBS until 54 h postmortem and then constant underestimation up to 1008 h, but only with the Megyesi et al. [19] method.

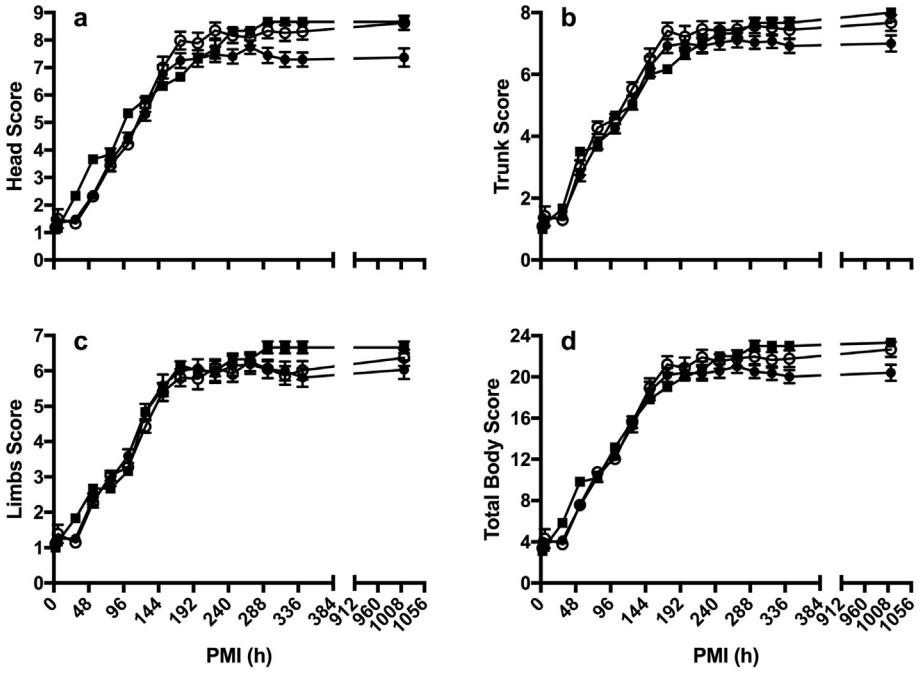

Fig. 5. Decomposition body scores of pig (*Sus scrofa domesticus*) carcasses in Palolo Valley, Oahu, Hawaii using the scoring method developed by Keough et al. [30]. Decomposition body scores were generated by carcass region including Head and Neck (a), Trunk (b), and Limbs (c). These scores were them summed to generate a Total Body Score at each PMI (d). Decomposition body scores were generated in real-time (■) and using 2D digital colour photographs. Photograph decomposition scores were generated by observers in the USA (○) and the UK (●) (n observers in each group = 9). Bars represent standard error where n = 9.

3.5. Photographs: the USA and UK groups

The decomposition body scores generated from the photographs after Megyesi et al. [19] did not show any significant difference between the USA and UK groups ($p > 0.05$). No significant difference in the TBS and Limbs decomposition scores generated after Keough et al. [30] was observed ($p > 0.05$) while the Head/Neck and Trunk scores differed significantly between groups ($F_{2, 60} = 4.02$ and $F_{2, 60} = 2.94$, $p < 0.05$, respectively).

3.6. Real-time versus photographs: correlation between mass loss and Total Body Score

All TBS from both groups were significantly positively correlated to carcass mass loss ($p < 0.001$) (Table 3). Real-time TBS was always more strongly related to carcass mass loss than photograph scores. The UK group photographs scores were either equally (with the Keough et al. method [30]) or more strongly (with the Megyesi et al. method [19]) related to mass loss than the USA group photograph scores.

4. Discussion

In summary, the present findings show that decomposition scores were significantly impacted by access to the remains and the scoring method used, while the photograph decomposition scores were highly replicable amongst the two groups of observers. In response to the first research question, the scores generated from photographs using the Megyesi et al. method [19] were significantly different than those generated in real-time, however, this difference was not observed when using the Keough et al. method [30], which supports the conclusion that the Keough et al. [30] method is more suitable for scoring the decomposition of exposed pig carcasses in a tropical climate. Also, photograph scores tended to be greater than real-time scores in the early postmortem period (< 54 h, 60 ADD) and then less after 54 h postmortem, which is consistent with the findings of Nawrocka et al. [48], while all scores were significantly positively correlated with carcass mass loss. In response to the second research question, high replicability of the photographic decomposition scores was identified across both groups of observers. It is thus logical to expect similar effects if the photographs were to be scored by other observers of comparable background. A more detailed discussion of the findings and their impact on the field of forensic taphonomy is proposed below. Overall, the present results lead to the conclusions that digital photographs may not provide a documentation of taphonomy as comprehensive and accurate as real-time observation, however photographs are an important source of information for the forensic investigation and the identification of the replicability of taphonomic conclusions drawn from photographs only is of critical importance for the forensic science community.

Table 3
Spearman's correlation coefficients between pig (*Sus scrofa domesticus*) carcass mass loss and Total Body Scores generated after Megyesi et al. [19] and Keough et al. [30] both in real-time and from photographs, over a period of 42 days in Palolo Valley, Oahu, Hawaii by observers in the USA and the UK.

	Spearman r	*P* value
Megyesi et al. [19]		
USA real-time	0.894	< 0.001
USA photographs	0.729	< 0.001
UK photographs	0.787	< 0.001
Keough et al. [30]		
USA real-time	0.911	< 0.001
USA photographs	0.726	< 0.001
UK photographs	0.726	< 0.001

4.1. Suitability of the scoring methods to evaluate decomposition from photographs in lieu of real-time observations

Significant differences between real-time and photograph scores using the Megyesi et al. method [19] were identified. These differences are probably due to the material being scored, as the Megyesi et al. method [19] was developed for human remains, although from 2D digital photographs, not pig remains. However, the environment of decomposition (the method was based on 68 cases from various locations in the USA, including Indiana (n = 15) and Illinois (n = 13), but not from Hawaii) as well as the experience of the observers [23,62] are also important considerations. The current findings demonstrate that the Keough et al. [30] method, that was developed for pig remains, appears to be the most suitable for taphonomic photographic evaluation of pig

remains exposed in a tropical savanna environment. The results indicate that the intrinsic differences between human and pig remains can impact the ability to accurately score decomposition, perhaps even more than the differences between real-time decomposing remains and photographs.

The present findings fit within the current, although scarce, literature on photographic analysis of taphonomy that demonstrated that high quality photography can provide reliable decomposition scores (e.g. 87.5% of observers generated similar scores [23]). However, when relying on photographs to evaluate taphonomy, it is important to consider that only taphonomic changes that are shown on the photographs can be scored [45], which calls for the analysis of complementary sources of information whenever available.

4.2. Replicability of the Megyesi et al. and Keough et al. methods on photographs of decomposing pigs

High inter-observer reliability scoring decomposition from 2D digital colour photographs can be achieved. Precisely, high consistency and agreement rates for body scores and TBS were reached amongst the USA group observers, indicating the replicability of photographic scoring of pig carcasses with both the Megyesi et al. [19] and Keough et al. [30] methods under the present conditions (environmental conditions and the composition of the group of observers). Also, high consistency and agreement rates for body scores and TBS were reached amongst the UK group observers, indicating the replicability of photograph scoring of pig carcasses with both the Megyesi et al. [19] and Keough et al. [30] methods under the present conditions. The Head/Neck and Trunk scores were found to be the most concordant among observers, independently of the method used, while Dabbs et al. [22] determined that the Trunk scores were the least concordant amongst sixteen observers using the Megyesi et al. method [19]. On the other hand, the present findings are consistent with Gelderman et al. [45] who developed a scoring method based on that of Megyesi et al. [19] and identified the Trunk as the area that reached the highest inter-observer agreement, across three groups of observers with different backgrounds and levels of education. Overall, the photograph scoring of the Limbs using the Megyesi et al. method [19] was found to be the least concordant and the most challenging for the observers. This is understandable as the method was developed for humans whose limbs, particularly the distal extremities, are different from that of pigs. Additionally, high inter-observer congruence was reached in the photograph TBS, regardless of the method used. However, significant differences were found at the smaller scale of body scores (Head/Neck and Trunk) when the Keough et al. [30] method was used. These findings bring an important contribution to the development of a baseline for forensic taphonomy. However, the limitations of the present study need to be discussed to enable further research.

4.3. The relationship between mass loss and decomposition scores

Investigating the correlation between decomposition scores and mass loss was an important complementary analysis because it provided an opportunity to compare a subjective decomposition measurement (TBS) to an objective, direct measurement of decomposition (mass loss). Consistent significant positive correlations between decomposition scores and mass loss were primarily viewed as a quality assurance measure, as was the observation that all decomposition scores were significantly impacted by PMI ($p < 0.001$) (data not shown). These correlations indicate that evaluating decomposition using photographs is consistent with an objective, direct measurement of mass loss, thus photograph scores can accurately reflect taphonomy. This phenomenon however requires further study.

The present results corroborate findings in the literature that also identified a discrepancy between decomposition scores and mass loss, highlighting that TBS plateaued prior to mass loss at the onset of Advanced Decay when fly larvae had migrated from the remains [7,57]. That discrepancy is probably because little visual changes occur during Advanced Decay although carcass mass may still be lost as soft and hard tissues decompose. A similar process may explain the discrepancy between decomposition and mass loss during the early postmortem period ($\leq$ 54 h, 60 ADD). This postmortem period was associated with little mass loss because decomposition was in the early stages (autolysis and early putrefaction) when the remains still have sufficient integrity to retain mass even though postmortem changes such as *livor mortis*, *rigor mortis*, skin slippage and marbling are observed [15]. Small increases in carcass mass during the early postmortem period were even reported in the literature [56,57,63]. This phenomenon is probably due to the accumulation of putrefactive gases and, possibly, an increase in the postmortem microbial biomass [63,64]. These discrepancies between mass loss and decomposition scores simply reflect two different aspects of decomposition. Similar discrepancies may be observed if other measures of taphonomy were used, such as carbon dioxide release [64] and gene expression [65]. It is important to consider these differences if using these measures to estimate PMI in forensic reconstructions as several complementary aspects of taphonomy need to be investigated in an integrated approach.

4.4. Future work and suggestions for best practice

Some limitations were noted in the present study. First, the scoring of the pig carcasses both in real-time in situ and from the photographs in the USA was performed by the same observers to investigate the consistency of the decomposition scores, however a month passed between the two scorings so that there was a much reduced chance for the observers to remember precisely the decomposition scores they allocated in real-time when scoring the photographs [23]. Second, although no significant differences were found between the decomposition scores generated from the three pig carcasses, regardless of mass and skin tone, anatomical and physical variations across the three carcasses made the scoring of decomposition from photographs a bit challenging for some observers. For example, the pigs showed different skin colours, including white/pink and black, which caused variations in the macroscopic expressions of decomposition. For instance, the black skinned pig did not show any *livor mortis*, contrary to the two light skinned pigs, a phenomenon also reported in the literature on humans with darker skin tones [45,66]. Furthermore, issues inherent to photographic analysis were noted (in 83.3% of the comments left by the observers), such as the lack of comprehensiveness of the photograph coverage [19,42,43,45]. The scoring of physical patterns with which descriptions in the original methods were associated with brightness or texture, such as the 'shiny/glossy' or 'leathery' appearance of the skin, as described by Keough et al. [30], were made difficult to observe from the photographs [45]. This is understandable as the Keough et al. [30] method was developed for real-time scoring of pig carcasses, and not for photographs, thus calling for adapted approaches when applied to photographs. Finally, the variations observed in the replicability of the decomposition body scores according to the anatomic scale considered (TBS or body scores) stress the importance of complementary study to (i) further investigate the potential issues that are introduced when only TBS is considered in forensic reconstructions and empirical studies, and (ii) better understand how to improve the accuracy of the scoring of the body regions.

To limit these issues and contribute to understanding whether digital photographs are suitable proxies for decomposing remains, further work is required. The repetition of the present experiment with other groups of student observers would provide the means to verify the replicability of the current results under similar conditions. In addition to this, it would be insightful to conduct the experiment with complementary variables, including expert taphonomists, to investigate whether the scoring of decomposition from digital photographs can be influenced by the experience of the observers [23]. Further studies

could also analyse larger numbers of carcasses and monitor their decomposition process for longer periods of time as the present results indicated an impact of time (PMI) on the decomposition body scores. Moreover, a larger and more comprehensive set of photographs would enable an investigation into whether such conditions could increase the correlation coefficient between decomposition scores and mass loss. Additionally, further study on the impact of the material being scored (real-time carcasses or digital photographs) and the context of the scoring (e.g. own time or limited time; home or laboratory) in the judgement and decision making of the observers regarding the decomposition scores would be greatly beneficial to identify potential cognitive factors that would then need to be taken into consideration in forensic reconstructions [67]. Such a knowledge base would allow the development of reproducible transparent approaches for photographic analysis in forensic death investigations.

The results of the present study enabled the identification of recommendations for best practice to visually score decomposition from photographs for two complementary scenarios and objectives: (i) in forensic investigations, both at death/decomposition scene and postmortem examination, and (ii) when conducting taphonomic studies. With regards to photograph coverage, it is important to be aware that extremities may be covered or fall out of view. In the current study, the head of the carcass fell out of the frame, causing the head/neck region to be poorly visible on the photographs and inaccuracy in the scoring of this body region. The use of frames that encompass the whole carcass is thus advised. Extensive photographs must be taken at the location of discovery of the remains to document the context of discovery of the remains and to enable subsequent interpretation of the remains relatively to their environment of decomposition. This procedure also enables the documentation of the state of preservation of the remains before being moved and analysed, which can be disruptive and cause a loss of evidence. Photographs of the remains from various angles and distances (including close-up photographs of the head/neck) are recommended to enhance the chances of accurately evaluating the decomposition stage and, thus, reaching accurate postmortem conclusions. To ensure standardisation and comparability of the photographs, it is advised that all photographs are taken from permanent landmarks in the vicinity of the remains. Suggestions can also be made to improve the calculation of TBS. To limit the occurrence of simple errors in the sum of the three body scores in view of calculating the TBS, it is recommended that TBS is systematically calculated in an automated way directly at the time of data collection (e.g. with a calculator or a programme like Microsoft Excel), if time and resources allow, or otherwise carefully cross-checked in a second phase. Future studies will enable a better understanding of the issues pertaining to taphonomic photographic analysis and lead to more detailed recommendations for best practices.

5. Conclusion

This study investigated whether there was a similarity between decomposition body scores generated in real-time and those generated from 2D digital photographs using two published scoring methods, and whether photograph decomposition scores could be replicated between different groups of observers. The findings indicate that similarity was only observed when the Keough et al. [30] method was used, but was not with the Megyesi et al. [19] method. Although inability to access decomposing remains in real-time can significantly impact the evaluation of the decomposition changes, the observers in the two groups consistently generated similar decomposition scores, thereby demonstrating a high repeatability of the two scoring methods both in real-time and from photographs. These preliminary results contribute to building a baseline for forensic taphonomy in exposed outdoors contexts and provide valuable new insights into forensic photograph-based reconstructions. The findings will be usefully supplemented by further research to better understand the variations observed in the decomposition scores according to the scoring method used. Such study will strengthen the knowledge base on forensic taphonomy and enable the development of robust evidence-based approaches for the interpretation of postmortem conclusions.

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Declaration of interest

None.

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