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Delayed decompositional changes in indoor settings among Tibetan monastic communities in India: A case report

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ABSTRACT

Within the fields of forensic anthropology and forensic medicine in general, the ability to provide accurate estimates of time since death that minimize error, maximize precision, and consider a multitude of variables is a critical component of all forensic and medicolegal investigations that focus on the identification of human remains and the circumstances surrounding death. In comparison with many forensic cases where date of death is typically unknown, we begin with a known postmortem interval and progressively assess, through external testing measures (temperature, skin elasticity and skin color changes) followed by photography and videography, decompositional changes over time. This work seeks to provide well-described cases with documented biological parameters to propose hypotheses for future research. Field team members observe and record any decompositional changes associated with the states of algor, rigor, and livor mortis, as well as progressive changes in

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skin color and tissue integrity in an environment where variability in climate and ecological factors may vary from case to case. The two cases were followed for 31 (postmortem interval [PMI] 38) and 19 (PMI 27) days in humid subtropical and tropical monsoon Köppen-Geiger classified climatic zones, respectively, where delayed decompositional and putrefactive changes observed are at odds with the anticipated rate and expected suite of biological changes occurring within an indoor permeable setting following clinical death. Within this taphonomic context, we also address the value of describing and documenting postmortem intervals in a closed subpopulation from which some individuals are recognized for exhibiting attenuated decompositional changes. This study emphasizes the importance of addressing understudied and underrepresented regions, climates, and cultural contexts for furthering research into the factors that may contribute to the understanding of the early stages of the PMI period and improve the precision of PMI estimates more broadly.

1. Introduction

Over the last four decades, the field of forensic sciences and, particularly the subfields of forensic anthropology, medicine, and pathology, have made significant progress in their ability to more accurately estimate time since death through access to and assessment of actualistic studies of human remains throughout the postmortem period [1,2]. Recent machine learning methods train on databases of such cases with their bioregional environmental conditions to provide predictive assessments of new cases [3]. Such research studies allow for unique opportunities to investigate the rate and range of differential decomposition in various settings across this critical interval of biological change both in outdoor and indoor environments. Until these developments, the systematic study of long-term body decomposition had apparently not advanced substantially since the 13th century when Song Ci, a Chinese physician in China known as the world's first forensic entomologist, made his postmortem assessments that informed publication of his coroner's manual that became the official standard for generations in China [4]. Early on, a broad set of "stages of decomposition" were established [5], along with factors that can contribute to the changes observed in each stage, especially in the early postmortem interval. Methods of assessing temperature gradients and related observations of the state of livor mortis or rigor mortis have informed estimates of the initial hours or days after death [6,7]. Classically, the assumption has been that shorter time frames limit the scale of error for recent deaths and that the scale of error will increase logarithmically as the time frame of the postmortem period increases [3]. For longer time frames of days to years in PMI estimations, methods have comprised: (1) visually identifying the stages of decomposition [8–10]; and (2) assaying biochemical markers correlated with such decompositional stages [11–14]. Nevertheless, much research—most of which is ongoing [3,9,10,14–21]—is still needed so as to characterize the duration of each stage and also to improve the precision of PMI estimates across geographic regions, climates and cultural contexts. Where differential decomposition can be visually appreciated and scientifically measured, a clear understanding of the postmortem processes requires observing and explaining the non-random distribution of external and internal changes of the early postmortem interval in specific climate zones, the overall physiological condition antemortem, and the variables that may help explain the presence and patterning of postmortem changes. In a medicolegal context, such observations and explanations are also often key to determining if a body may have been moved from one location to another or from one position to another, and they also serve to highlight areas of the body that may exhibit ante- and perimortem trauma. This case report details two cases from a current observational pilot study, built on an international collaboration, initiated with consent of the respective Tibetan communities in India and implemented by trained field team members. In these cases, delayed decompositional and putrefactive changes observed are inconsistent with the anticipated rate and expected suite of biological changes occurring within an indoor permeable setting following clinical death. This article aims to present these well-described cases with documented biological parameters to propose hypotheses for follow-up research.

1.1. Background

In the Tibetan cultural tradition, following clinical death, most bodies are left undisturbed for three or more days once cardiopulmonary function has ceased, or in the hospital context, even once brain activity has ceased, to allow for full transition of what they see as the subtle consciousness [22]. This Tibetan cultural practice is related to the notion that, for Buddhist contemplative practitioners with sufficient skill, the process of dying is an important physio-temporal window for spiritual practice. For advanced practitioners, a specific postmortem meditative state is described where the individual will remain in an upright or reclining posture for days or weeks beyond this three-day postmortem period without detection of any overt signs of decomposition. This state, known as *tukdam* (Tib., *thugs dam*), is considered by the tradition to demonstrate a uniquely important attainment in that individual's final transition from this life to the next [23]. While everyone is said to undergo a similar process during the time of death, it is thought that only advanced practitioners of specific contemplative practices will be able to transform that process into a meditative state.

Within the framework of this cultural interpretation, there are frequent opportunities in the Tibetan cultural context to observe postmortem changes without disturbance to the decedent, providing a setting for systematic observation of long-term body decomposition akin to conditions for actualistic studies described above. This study investigates and presents a small subset of these cases, documenting the postmortem state of respective changes in decomposition and putrefaction daily.

1.2. Cultural Context

The postmortem signs of *tukdam* have been documented in detail as early as the 14th and 15th centuries [24,25] but are theorized to occur much earlier in time, since Tibetan contemplative communities were engaged in the relevant practices as early as the 11th century, if not before. In most accounts, the individual in the state of *tukdam* will be left alone in a closed room undisturbed, at times for weeks, with attendance by just one or two persons close to the individual. Indications that the state has ceased include the slumping of the head for cases in which upright posture is held, detection of a putrid odor, the presence of insect activity, or observation of accelerated signs of decomposition [25].

This pilot study aims to observe individuals as they transition through the dying process through and beyond clinical death. Tukdam states are often initially recognized because a body does not exhibit normative signs of decomposition or putrefaction [18] after the typical three days that decedents are monitored. The study team is therefore usually notified and called upon to document the presence or absence of these changes at least three days postmortem, so our data generally does not include incipient postmortem changes prior to the third day after clinical death. To provide examples, we have selected two of the longer cases for detailed presentation; both cases involve Tibetan monks and occurred at their respective monasteries.

To our knowledge, this Case Report presents the first forensic observations of delayed decomposition of a postmortem state reported in Tibetan communities.

1.3. Study Approach

Contrary to many forensic cases where date of death and by extension the postmortem interval is unknown, this case study begins with that key baseline information and progressively follows the decompositional process through twice daily photographic documentation and videography from the same angles and under a combination of artificial and natural lighting. These cases were also observed independently through detailed photographic images by two forensic experts—a board-certified forensic anthropologist from the US and a lead government forensic pathologist from Russia with cumulative 60 years field experience—and included on-the-ground assessments by forensically trained field team members focusing on the visual classification of the stages of decomposition associated with the states of pallor, algor, rigor, and livor mortis as well as visual indications of late postmortem changes.

Also recorded are the presence and rate of skin color changes across axial and appendicular segments of the body using an objective scoring of skin color that employs the Munsell color system cards [27–30], which represent standardized chroma, hue, and value as an explicit and repeatable measure for skin color. To the best of the authors' knowledge, this study represents the first forensic use of Munsell color cards to describe organic skin color changes, though it was originally designated as suitable "for the evaluation of skin, hair and eye color in anthropology, criminology, pathology and forensic medicine" [30] and has been used to document skin color changes in dermatologic oncology [29]. For more information on this applied measure, see Table 1, and for illustration of the overall study methods including this study's particular application of the Munsell color measure, see Supplement 1.

Skin color and tissue changes, if present, are also noted and described by location. External body and ambient room temperature and humidity readings are typically taken twice daily and contextualized by daily outdoor high and low temperature and humidity readings provided by weather stations within a distance of 10–20 km from each monastery.

Between 2019 and 2023, the study team has followed 28 cases that exhibit unexpected and non-normative delayed decompositional changes. Most of these cases (n=26) occurred in the context of a monastic community that experienced approximately 200 deaths in a population of 9975 monastics during this period. Due to the significant cultural value ascribed to the phenomena, cases of tukdam states are reported to the study team with high reliability by the participating institutions. Likewise, physiological state of the body in tukdam cases are widely visible in the community, especially prior to cremation. This case report tracks two of the longer cases that were observed over a period of 31 (PMI observed – 38) and 19 (PMI observed – 27) days, respectively, after the cessation of all brain and vital sign activity. The selection of these two cases in particular allows us to observe and present our findings in more descriptive detail and through sequential photographic records (Supplement 2 and 3) during an extended period of time.

2. Case Reports and Observations

2.1. Case 1 – North India, Dharamsala area, Gyutö Monastery (Elevation 1457 m/4780 ft & Latitude 32°14'22.1"N 76°19'32.8"E; Köppen-Geiger 'Cfa' climate class, Humid Subtropical zone)

This case is that of an 86-year-old male who died of Covid-19 in early March 2021. He had been admitted to the local hospital per local Covid-19 policy, but having refused all treatments for 2 days, was transferred from the hospital still alive to a bed in the monastery where he performed his final meditative practices. He continued normal dietary intake through hospital admission and release, reporting normal appetite; and engaged in no fasting practices. Following clinical death, his body was lying supine on a bed covered with a thin large yellow shawl, made of a cotton blend. The bed was located in a first-floor cement-walled room with natural (passive) ventilation adjacent to a window that allowed for sunshine to filter in during the course of each day, comprising the primary context for all data collection sessions. A warm-

Table 1
Measures assessed in cases for forensic analysis.

Measures Collected			
Measure	**Data Collection Method**	**Frequency**	**Details**
Body surface temperature	Infrared thermometer	Twice daily	Assessed at 12 pre-specified body regions
Ambient air temperature	Digital temperature sensor	Twice daily	Placed 1 m from body
Humidity	Digital hygrometer	Twice daily	Placed 1 m from body
Skin pallor and color changes	Nuanced standardized color matching with Munsell color cards using predefined alphanumeric identifiers of hue, chroma, and value	Twice daily	Munsell color cards were chosen to provide standardized assessments of subtle skin pallor and color changes of postmortem period; Individual Munsell color designations were utilized in order to minimize subjectivity and provide consistent readings in assigning individual skin color changes
Skin turgor, slippage, and integrity	Study team assesses skin elasticity with physical pinch test on each extremity with video documentation	Twice daily	Independent third analysis provided by forensic pathologist and anthropologist in Russia and US, respectively
Purge fluid and other orifice excretions	Study team documents observations and photographs each orifice; excretions collected for biological analysis	Twice daily	Independent third analysis provided by forensic pathologist and anthropologist in Russia and US, respectively
Insect activity presence	Study team documents and photographs insect (s), if present	Twice daily	Independent third analysis provided by forensic taphonomist and anthropologist in US
Odor presence	Study team documents degree of odor presence and quality	Twice daily	Current observations conducted by study team with third party naïve assessor; future cases to include collection of volatile organic compounds in air proximal to decedent
Measures Culturally Not Permissible for Collection			
Measure	**Data Collection Method**	**Rationale**	**Details/Adaptation**
Internal body temperature	Temperature procured rectally or through another skin portal	Cultural restrictions forbid penetration of orifices	Infrared camera and thermography have been conducted on cases proximal to liquid nitrogen source for equipment operation
Evaluation of dependent areas	Turning body on side for observation and scoring of dependent areas	Cultural restrictions forbid moving body due to perceived sensitive state of remnant consciousness	Study team documents and photographs visible dependent regions adjacent to dependent surfaces

toned compact fluorescent light overhead turned on for a couple hours each evening provided the setting for a few additional data collection sessions. The window was closed but not tightly sealed and did not include a window screen. There was also a gap noted under the door to the room. The average indoor air temperature throughout the study was 21°C but reached highs of 24°C and lows of 20°C; ambient outdoor temperature reached highs of 25°C and lows of 18°C. Humidity ranged greatly in fluctuations from 21% to 80% daily. See Fig. 1 for body, ambient room, and outdoor temperatures and humidity over the study period.

His medical history documents that he suffered from type 2 diabetes and hypertension and may have had a possible active case of tuberculosis at the time of death. His medications comprised metformin and a single antihypertensive agent, mostly likely lisinopril. Because access to the body was delayed by cultural factors, observations were initiated on Day 7 of the postmortem period and continued daily for another 31 days for a total of 38 days after reported clinical death. During the 31-day observational period, the large yellow shawl was removed, and the body repositioned on top of a single-ply cotton bedsheet atop clear plastic sheeting. Body surface (head, arm, chest, abdominal wall) and ambient air temperatures and relative humidity readings were taken twice a day at 0800 and again at 1500 hours. The first signs of late postmortem changes (green skin discoloration of the lower abdominal area and skin marbling) appeared for the first time on Day 12 postmortem, with progression of expected late postmortem changes from Day 13 until Day 38. Evidence for skin desiccation appears for the first time on Day 20.

No odor of putrefaction was noted by the field team until day 37 and there was a long plateau characterized by how the expected postmortem changes had slowed dramatically with rapid decay at the end (Day 38) of the observational period. Dehydration/desiccation, particularly to the facial area was appreciated as that area was exposed to considerable sunlight throughout the observational period. This external light and heat source almost certainly contributed to the observed tanning and differential mummification/desiccation of the face and head. The upper torso exhibited the least observable change in comparison with other areas of the body. Possible fly oviposition or white fungus in the narrow space between the closed upper and lower eyelids and adjacent to the left lateral elbow may be present, but photographs were not confirmatory; no documentation to that effect was provided. In one image captured on postmortem Day 17, a single fly was noted on the tip of the decedent's nose. The team hypothesizes that the absence or delay of egg-laying behavior typically seen during the early phases of decomposition may be related to the slowed rate of overall body decomposition observed in this case. Additionally, the nasal aperture and mouth were filled with cotton limiting and/or delaying possible oviposition. Lividity was exclusively present on the plantar surfaces and lateral aspect of both feet even though the body was supine and expected lividity should have been observed on all dependent areas. The heart region of the central body (thorax) was reported to maintain a "freshness" (Figs. 5, 6 below) and was devoid of signs of putrefaction until very late in the process. See Supplement 2 for twice daily images across body regions of assessment period. This attenuated decomposition is significant with respect to the expected "normative process" of decomposition, particularly for this Humid Subtropical climatic zone (Köppen-Geiger classification of 'Cfa') [31–34] and the ambient environmental conditions (Fig. 1).

When forensic pathologists describe what they observe as a normal decompositional event, they refer to the enzymatic breakdown of cells and organs (autolysis) after death that can be significantly altered by external temperature (cold will delay; heat will accelerate); as a result,

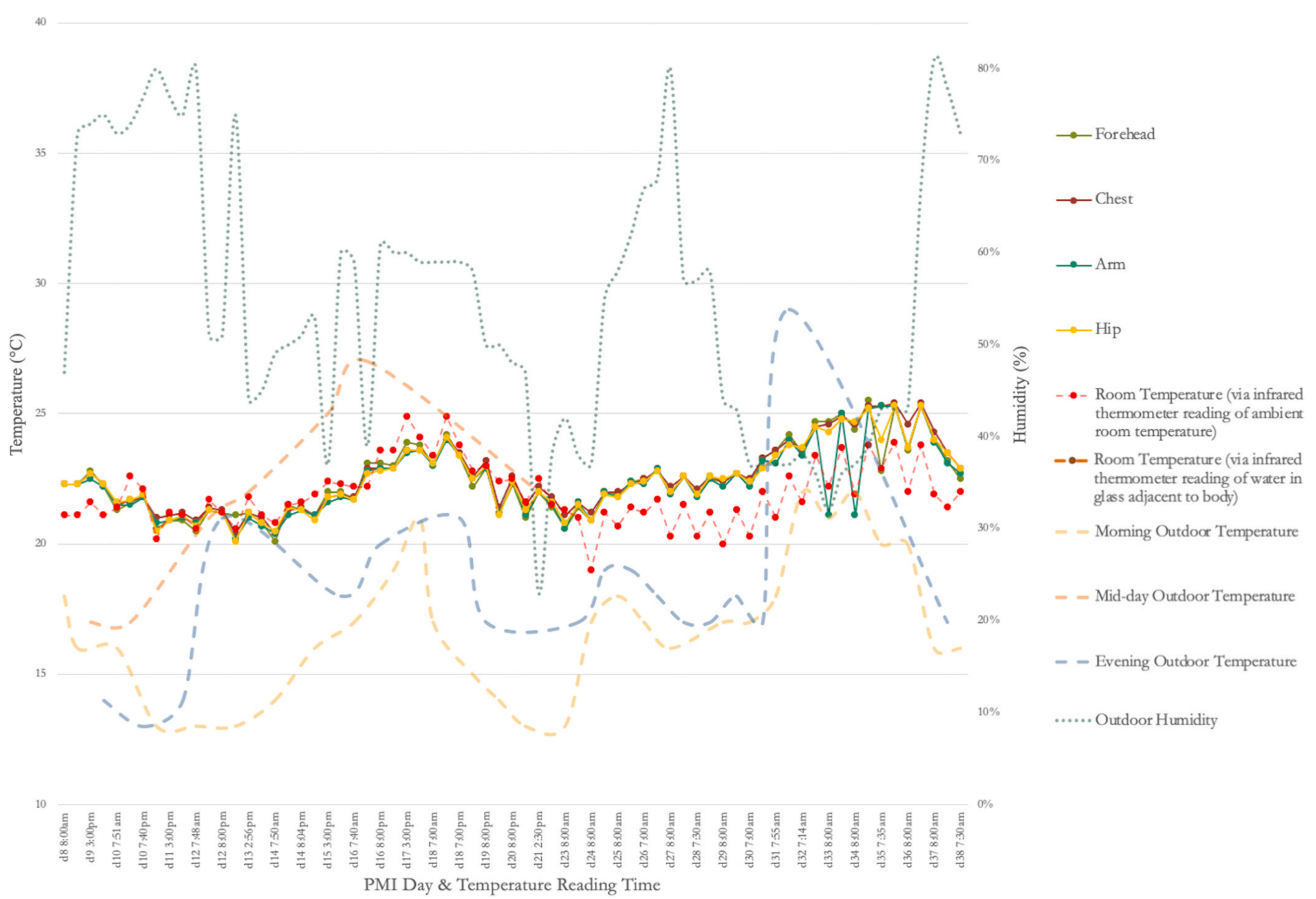

Fig. 1. Case 1 temperature versus time - body regions, ambient room, and environment.

Fig. 2. Ceremonial white silk scarf (katak) covering decedent.

Fig. 3. View of body, Day 9 postmortem.

this process of autolysis can be variable depending on postmortem environmental conditions. Organs with higher enzymatic activity will begin to breakdown more quickly. At the same time, the process of putrefaction begins in the gastrointestinal tract where bacteria multiply

Fig. 4. Close-up of head, Day 19 postmortem.

Fig. 5. Day 36 postmortem.

and fermentation occurs which then spreads throughout the rest of the body leading to observable changes that include a greenish/black discoloration of the lower abdominal region, followed by the head, neck and shoulder areas. Marbling of the skin and bloating of the face and body soon follow [31,35]. Sepsis accelerates the timing of putrefaction, and body habitus will affect the pace. Typically, fluids will drain from the nose and mouth, but in the two cases presented here, cotton wool was placed in both orifices to identify fluid color for cultural reasons, potentially restricting purge fluids.

Fig. 6. Day 37 postmortem.

2.2. Case 2 – South India, Mundgod area, Gaden Shartse Monastery (Elevation 567 m /1860 ft & Latitute 14.97°N 75.03°E; Köppen-Geiger 'Am/Aw' climate class, Tropical Monsoon/Tropical Savannah zone [36])

This case is that of an 83-year-old male, who, in early January 2022, after a nine-day hospital stay, died of a pulmonary infection comprising a clinical diagnosis of Covid-19 (though with negative PCR lab test) compounded by fungal and possible bacterial infection with suspected septicemia. Bronchoalveolar lavage cytology indicated presence of fungal hyphae, without presence of malignancy among squamous cells. Similar to the prior case, he suffered from type 2 diabetes and hypertension, and also experienced benign prostatic hyperplasia. He had recovered from mild paralysis on the right side of his body through sustained medical treatments, but experienced relapse in 2019 leaving him unable to stand on his right leg. On admission to the hospital in Hubli, his prior medications of metformin and tamsulosin were continued. He was also given the antibiotics ceftriaxone and meropenem (until clinical death); several anticoagulants (enoxaparin, apixaban, and aspirin); the antiviral medication remdesivir and the steroid dexamethasone, which were both started the day after admission and continued for 4 days; inhalant breathing treatments (acetylcysteine, ipratropium bromide/salbutamol); an antipyretic (paracetamol); intravenous fluids intermittently, including the day before he passed; cough syrup; and proton pump inhibitors and histamine blockers.

An investigation of the literature was conducted to evaluate what is known about the effect of pharmacotherapy on the rate of decomposition. While some studies are available that discuss the proposed impact of morphine on decomposition (perhaps delaying insect attraction and development rates), little is available in the literature [37] to guide our assessment of how his chronic and acute medical treatments may have impacted the rate of decomposition that was observed. Researchers at the University of Tennessee-Knoxville are currently studying this question [38]; we anticipate their results will increase our understanding of this important area.

Once clinical death was declared, the body was transferred to the monastery to allow for completion of the dying transition period as per cultural custom and recognition. Access to the body was delayed by cultural factors as with the prior case, and observations were initiated on Day 8 of the postmortem period and continued daily for another 19 days, totaling 27 days after clinical death. Upon arrival by the study team, the body of this decedent was lying supine covered by a yellow shawl on a bed enwrapped by a single-ply cotton sheet atop a single layer of plastic sheeting. Starting from the first day of study observations, the yellow shawl was removed and body exposed twice per day during each forensic examination. As is the custom for his spiritual tradition, a light dab of vermillion powder had been placed on his forehead, throat, and lower sternum, and navel. Attendants to the deceased had placed a handful of cotton over the genitals to retain cultural modesty upon photographic documentation by the team. The photographic documentation of this individual began on Day 8 postmortem and continued until the 27th day after death. Calibrated body surface (head, arm, chest (right, left, and central regions), pelvic abdominal wall) and ambient air temperatures and relative humidity readings were taken twice a day at 0800 and again at 1500 hours. The average indoor air temperature throughout the study was 22.3±1.8°C, and body surface temperatures ranged from 21.7 to 22.3°C supporting algor mortis cooling. See Fig. 7 for body and ambient room temperatures over the observation period. The average indoor relative humidity lows were 38.0±3.6% with higher percentages of 68.2±7.3% occurring during the first half of each day.

The body was examined under natural and artificial lighting (distal incandescent and proximal cool-toned compact fluorescent light combination) in a room with passive ventilation. Skin color identification using Munsell cards assessed at eleven body regions (Fig. 12) provided formal scoring of skin color changes in predesignated points over assessment period (Fig. 13). The Munsell colors demonstrate a steady decrease in value over the course of the assessment with a brief increase in chroma at value change inflection points for several regions and time points. Although the readings validate our original prediction of a steady decrease in value across the postmortem period, the brief increase in chroma at several points is unexpected and seems to represent localized tissue changes during the underlying decompositional process that present with a relative "brightness" in color saturation for several time points. Though the Munsell color identifiers cannot demonstrate precise skin color readings, they can be used objectively and effectively to show trends in skin color development. Additional cases with these applied measures will help us test this prediction. Specific decompositional presentations of condition are noted in more detail below from the twice daily observations.

On Day 8 postmortem signs of green discoloration of the abdomen and anterior and lateral surfaces of the chest appeared along with early development of a putrid venous network on the right lateral chest surface. Over the subsequent three days, Days 9 through 11, the green discoloration on the right and left lateral surfaces of the chest increased slightly and local skin desiccation presented on the surfaces of the anterior chest, left shoulder, face and ears. Fingers and soles of the feet showed incipient desiccation and darkening of the skin and swelling on the palmar surfaces of both wrists. Minor desiccation increased on Days 12 and 13. Green discoloration progressed on the chest and abdomen for Days 14 through 16, with signs of discoloration on the lower extremities appreciated. New areas of desiccation presented on lower extremities and the upper extremities began darkening. A white-colored mold/fungal growth appeared across the skin of axillary and inguinal regions as well as on nasal orifices. On Days 17 and 18 green discoloration progressed and upper and lower limbs developed putrid venous networks.

A plateau across decompositional changes occurred from Day 19 through 21 except for the development of mold in specified regions. Days 22 through 27 exhibited a rapid increase in desiccation across skin surfaces such that by Day 27 only areas of the chest and abdominal surfaces appeared unaffected.

The succession of significant late postmortem changes of

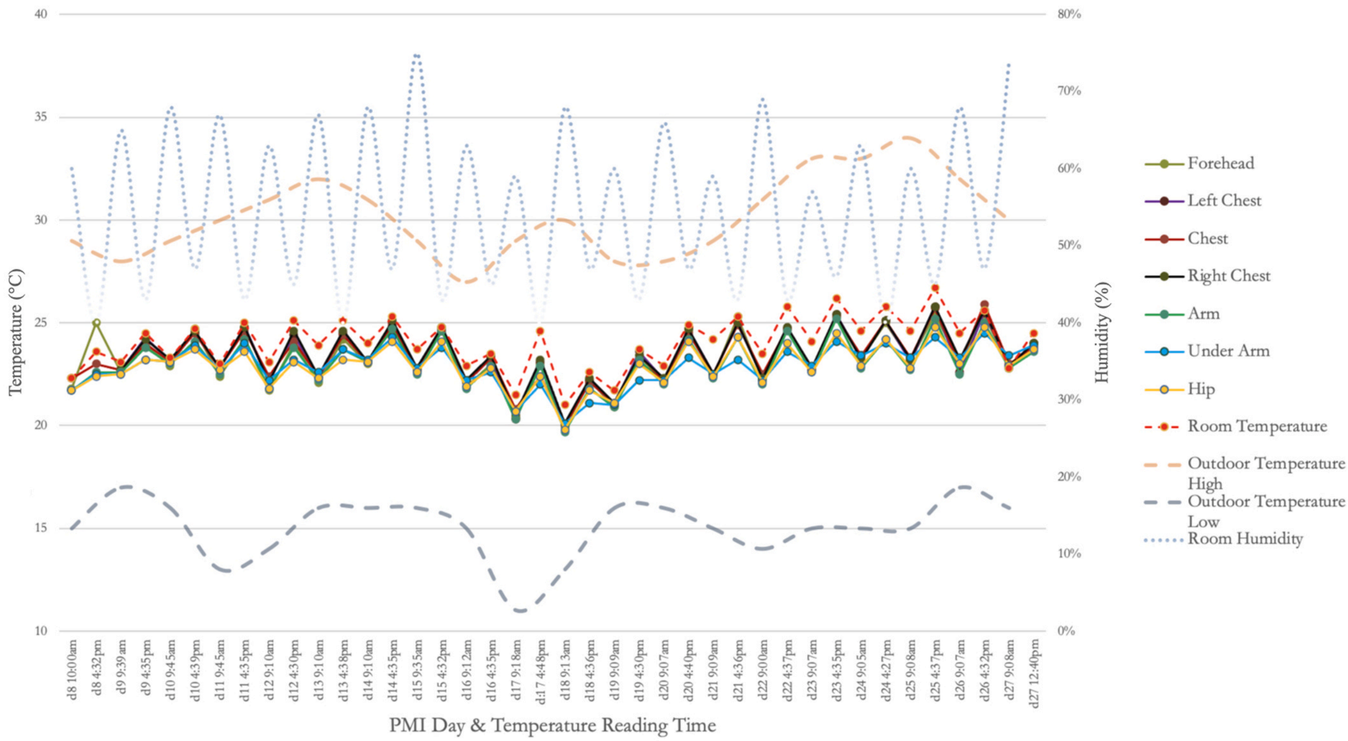

Fig. 7. Case 2 temperature versus time - body regions, ambient room, and environment.

discoloration at the head and trunk (see [26]) were only detected between Day 8 and 16 yet still progressed at a markedly slow rate compared to expected changes at such temperature and humidity. Desiccation, most pronounced by Day 18, rapidly developed from Days 22–27. Minor bloating did not occur until Day 27, simultaneous with fluid purge from the genital and oral orifices. See Supplement 3 for time course of images documenting changes. No insect activity was noted throughout the investigatory period.

The body showed delayed decomposition until putrid odor was detected on the 27th day postmortem at which time the investigation was terminated because of the consensus by the guiding senior Tibetan cultural experts that the state was complete.

3. Discussion

We know that after clinical death, a body (under normative conditions) passes through the stages of autolysis and putrefaction (including internal bacterial proliferation) in a generally predictable sequence [26] and time course for temperate regions. If, however, the expected sequence of decomposition is altered from expectations, the estimation of an accurate postmortem interval may be skewed [17,39]. This is an important consideration in medicolegal cases where the PMI is unknown and has yet to be established. The results of actualistic studies undertaken by forensic anthropologists [40,41] and atypical postmortem changes recognized by both forensic anthropologists and forensic pathologists have demonstrated that preexisting ante- and perimortem trauma (including antemortem medical interventions) may accelerate differential decomposition by artificially introducing entry point(s) for animal, bird and rodent depredation in both indoor and outdoor settings [42]. They also serve as an additional portal(s) for accelerated insect oviposition. While those variables would be vital to address in an outdoor situation they are not addressed here because both cases were followed in an indoor setting and we are seeing delayed, not accelerated decomposition in both instances presented here. Likewise, the two most commonly used formulae for estimating PMI, Megyesi et al. [9] and Vass [10], both of whom rely on temperature and the latter additionally relying on relative humidity for their estimates, do not apply to the indoor context. Relying on three decades of research at the Anthropological Research Facility in Knoxville, Tennessee, to develop his formula, Vass's method has been shown to be more precise even for anaerobic decomposition than Megyesi and colleagues' [9] Total Body Score combined with Accumulated Degree Days even in regions similar to those described herein [16]. However, neither have provided accurate assessments of the PMI in the two cases presented. Recently, Weisensee and colleagues developed a web-based collaborative application called geoFOR [3] that utilizes ArcGIS and machine learning to develop improved PMI predictions. The tool allows for collaborators to enter case information and automates the collection of environmental data to deliver a PMI prediction through cross-validating machine learning PMI predictive model results. However, the database currently only contains entries from the US, drawing on the longitudinal studies from the human decomposition facilities described above as well as medicolegal investigations in the US so is limited in its applications for cases in other countries for now. With the impacts of climate change predicting a decrease in the accuracy of formulae used for PMI estimation in outdoor environments even in regions where levels of precision are quite good [43], understanding variation in both indoor and outdoor environments across regions is critical and a web-based collaborative tool will become even more important with entries from locations where cases are underreported such as described here.

Of all potential variables, including seasonality, temperature, humidity, body corpulence, and access to insects, temperature is considered the most important variable influencing "dwell-time" in a particular stage and the overall velocity of the decompositional process [35]. Such findings have been observed during early and ongoing studies performed at the Anthropological Research Facility in Knoxville, Tennessee and elsewhere [2,44,45]. Both cases presented here exhibit attenuated decomposition amidst substantially elevated body temperatures of 20–25°C. In terms of the effects of humidity, higher humidity is recognized to lead to faster decomposition by accelerating chemical reactions and insect activity, and low humidity is linked to delayed decomposition or, in significantly low humidity, a pronounced

Fig. 8. (A-D) Views of body, Day 8 postmortem.

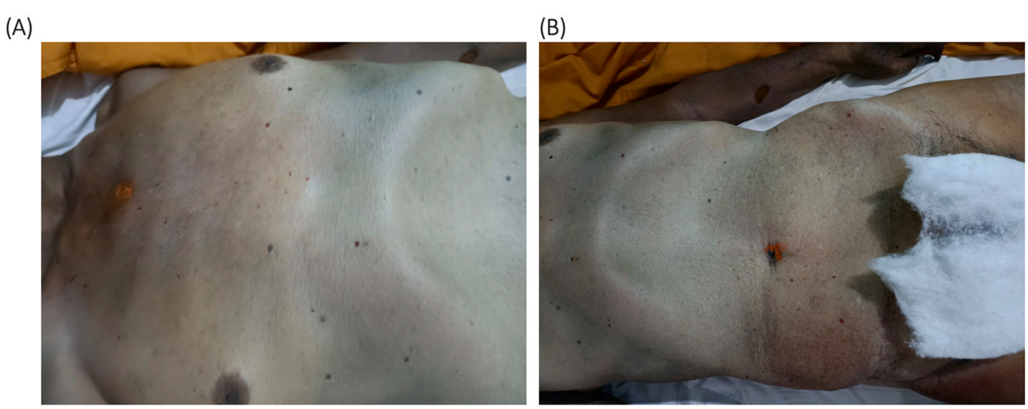

Fig. 9. (A, B) Chest and abdomen, Day 16 postmortem.

attenuation of decomposition leading to natural mummification [17]. Notably, the indoor humidity range for both of our cases was on average between 40% and 75%, and given what is known about the effects of humidity, such a relatively high interior humidity range documented throughout the course of assessment is unexpected in the face of the slow decompositional rates observed.

Our early observations in these two cases highlight both practical and theoretical questions: 1) If we assessed the decompositional changes observed here without having the benefit of knowing the confirmed date of death and/or the duration of the postmortem interval, how might this affect our time since death estimates? 2) Can we posit a plasticity in the body's postmortem decompositional response that may be related in part to the persistence of some form of coherent activity, which the Tibetan traditions interpret as connected to a lifetime of particular contemplative practices that allow for persistence in this state? And, finally, 3) Could the two cases presented here represent extreme examples (i.e. outliers) rather than the norm for cases recognized in this state?

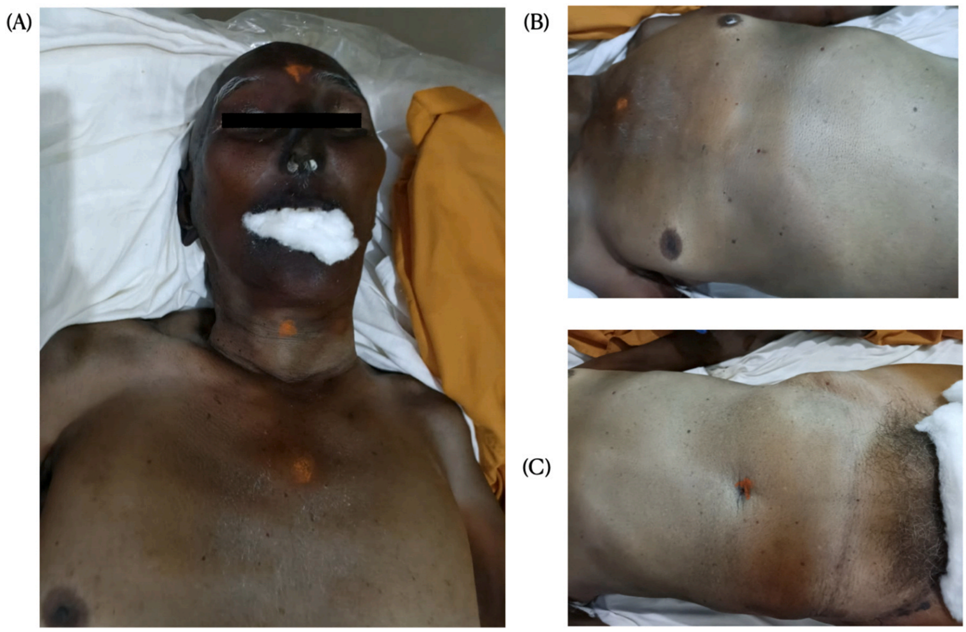

Fig. 10. (A-C) Face, chest and abdomen, Day 27 postmortem.

Fig. 11. (A-D) Upper and lower extremities, Day 27 postmortem.

As with all research studies, it is important at this early stage to articulate recognized constraints. First, as noted earlier, it was not possible to document incipient postmortem changes because access to the deceased immediately following clinical death was delayed by several days as a result of cultural prescriptions to wait a minimum of three days before the *tukdam* state is declared. In those cases where initial phases of expected decompositional changes may be delayed or absent, this may be less of a concern. Second, although internal body temperature is clearly relevant to the decompositional process, procuring the internal body temperature rectally or through a skin portal was not possible due to cultural restrictions. Third, because of the body position of the decedent and cultural restrictions on moving the body, there is currently a limited ability to view and score dependent areas of the body. Fourth, a full medical history is not always available, and if it is available, typically not until after the observational period ends. This may, however, be to our advantage by limiting potential study bias among observers and our research teams. Fifth, minimal research evaluating the effect of pharmacotherapies on the rates of decomposition limits our ability to assess how chronic and acute medical treatments may impact observed physiological changes in the postmortem period.

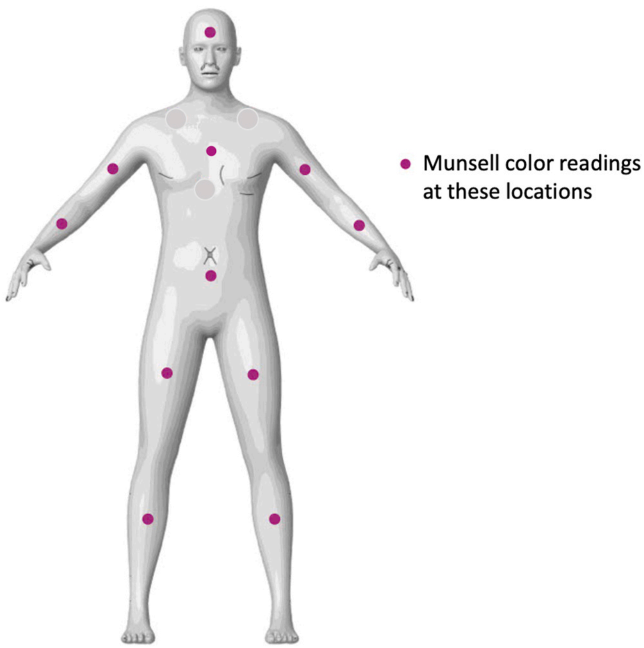

Fig. 12. Body regions of skin color identification using Munsell measures.

Likewise, limited published literature documenting postmortem changes across diverse populations, skin colors, and geographic regions and climates constrain comparative cases. Such lacunae in the literature emphasize the need for greater forensic reporting globally.

A few situational constraints have also occurred. In Case 1, the context of Covid-19 meant that the team relied on one team member only and could not use its normal instruments for investigation (i.e., Munsell color cards and greyscale/color calibration tools were inaccessible). Thus, such unusual contexts may differ from case-to-case and by location, such that data collection and reporting can exhibit some heterogeneity across cases as with the two presented here. The latter being performed by field team members directly and the former in which the study team leads instructed data collection remotely. Except during the twice daily assessments, for one of the cases presented in this report, monastic robes routinely covered the body and were found underneath, around or on top of the body and may have inhibited easy access to insects and may have delayed body cooling. Additionally, a ceremonial white silk scarf (*katak*) is placed by attendants/fellow monastics to honor the decedent. When the decedent is lying down, it is often placed over the entire body, or in our cases, retained over a portion of the body, like the genital area, to allow for examination by the study yet retain respectful modesty. In this geographical context of humid subtropical and tropical monsoon climates with matinal high humidity, cooling of the body is usually accelerated due to higher moisture concentration in the air, but monastic robes covering the body between assessments for our cases might have delayed cooling.

It is interesting to note that this particular monastic population engages in meditation practices that comprise decades of rehearsing for the death context through rigorous visualization practices [46]. Individuals who are expert in these practices are trained to consider the dying process as an especially effective opportunity for spiritual advancement, so for them death is generally welcomed and not feared, potentially minimizing the physiological stress response of the body. In addition, the region of the heart is used as a focal area of concentrative attention during these practices, and in the two cases presented here, the chest center has demonstrated delayed decomposition relative to other parts of the body documented. Other cultures also describe states of delayed decomposition among those who have engaged in devotional, contemplative, morally aesthetic, and ascetic practices [47–54]. This study aims to contribute observations of biological changes that may underpin some of such occurrences.

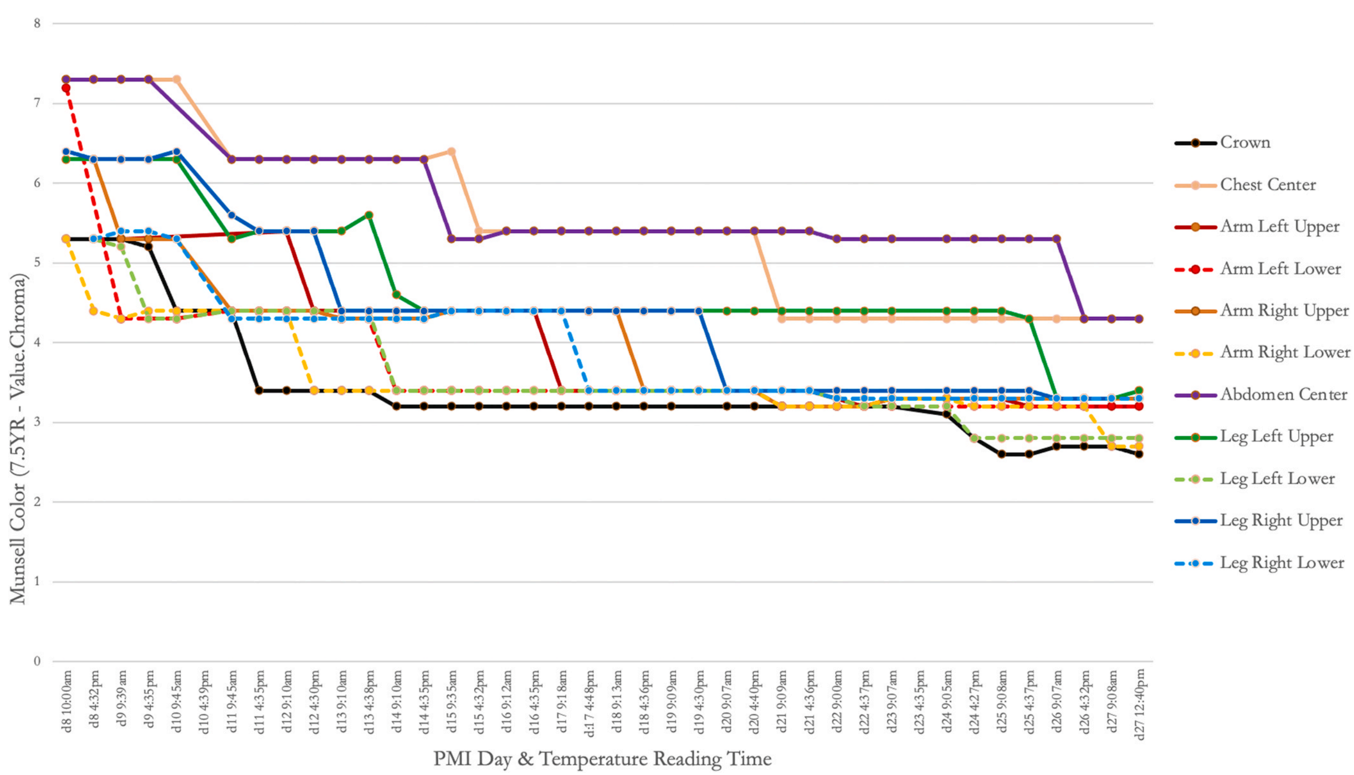

Fig. 13. Case 2 Munsell color identification by body region across time.

4. Conclusions

This case report highlights two cases where the recognition and documentation of deviations from the anticipated “normative” rate and pattern of decomposition in an indoor setting have been noted. We describe a rate of attenuated decomposition that reaches a plateau where putrefaction stalls, followed later by a rapid rate of body deterioration during the final period of observation. Though previously used to identify skin color changes for preventative measures in dermatologic oncology [29] and gastrointestinal mucosal color changes in gastroenterology [55], this is the first forensic use of the Munsell color system for the formal scoring of skin color changes throughout body decomposition. We document these developments thoroughly with the intent that it can be instructive to other forensic teams seeking a similar comparative instrument. In terms of its findings and methods, this case report is offered as a preliminary set of observations that we believe merit further systematic examination.

Ethical and IRB approval

Human subjects research was approved by the University of Wisconsin-Madison Institutional Review Board, IRB protocols no. 2013-0753 and no. 2016-1472; by Institute of the Human Brain, Russian Academy of Sciences [Ethical Committee Decision Protocol 17 October 2019); by Men-Tsee-Khang/Tibetan Medical and Astro-science Institute Research Ethics Committee; by Delek Hospital Human Subjects Research Review Board; administrations of Drepung, Sera, Gaden, Tashi Lhunpo, and Gyutö monastic institutions (Agreements on Regulations of the International Neuroscience Lab Units A&B from 13.12.2019), as well as the Private Office of His Holiness the Dalai Lama; World Medical Association (2013), Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects and the relevant overseeing cultural bodies of each participating monastic and medical institution. In all cases, the participants or their surrogates provided their written informed consent to participate in this study.

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Declaration of Competing Interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fsir.2024.100370.

References

[1] A. Ribéreau-Gayon, D.O. Carter, S. Forbes, Developing a new scoring method to evaluate human decomposition in a humid, continental (Dfb) climate in Quebec, J. Forensic Sci. 68 (2) (2023) 536–548, https://doi.org/10.1111/1556-4029.15201.

[2] D.J. Wescott, D.W. Steadman, N. Miller, K. Sauerwein, C.M.J. Clemmons, D. S. Gleiber, et al., Validation of the Total Body Score/Accumulated Degree-Day Model at Three Human Decomposition Facilities, Forensic Anthr. 1 (3) (2018) 143–149, https://doi.org/10.5744/fa.2018.0015.

[3] K.E. Weisensee, C.I. Tica, M.M. Atwell, C. Ehrett, D.H. Smith, P. Carbajales-Dale, et al., geoFOR: A collaborative forensic taphonomy database for estimating the postmortem interval, Forensic Sci. Int 355 (2024) 111934, https://doi.org/10.1016/j.forsciint.2024.111934.

[4] Sung T., Mcknight. The Washing Away of Wrongs: Forensic Medicine in Thirteenth-Century China. Ann Arbor: University of Michigan Center for Chinese Studies, 1981.

[5] W.C. Rodriguez, W.M. Bass, Insect Activity and its Relationship to Decay Rates of Human Cadavers in East Tennessee, J. Forensic Sci. 28 (2) (1983) 11524J, https://doi.org/10.1520/JFS11524J.

[6] M. Hubig, H. Muggenthaler, I. Sinicina, G. Mall, Temperature based forensic death time estimation: The standard model in experimental test, Leg. Med Tokyo Jpn 17 (5) (2015) 381–387, https://doi.org/10.1016/j.legalmed.2015.05.005.

[7] L.S. Wilk, G.J. Edelman, M. Roos, M. Clerkx, I. Dijkman, J.V. Melgar, et al., Individualised and non-contact post-mortem interval determination of human bodies using visible and thermal 3D imaging, Nat. Commun. 12 (1) (2021) 5997, https://doi.org/10.1038/s41467-021-26318-4.

[8] R.W. Mann, W.M. Bass, L. Meadows, Time since death and decomposition of the human body: variables and observations in case and experimental field studies, J. Forensic Sci. 35 (1) (1990) 103–111.

[9] M.S. Megyesi, S.P. Nawrocki, N.H. Haskell, Using Accumulated Degree-Days to Estimate the Postmortem Interval from Decomposed Human Remains, J. Forensic Sci. 50 (3) (2005) JFS2004017, https://doi.org/10.1520/JFS2004017.

[10] A.A. Vass, The elusive universal post-mortem interval formula, Forensic Sci. Int 204 (1) (2011) 34–40, https://doi.org/10.1016/j.forsciint.2010.04.052.

[11] H. Lutz, A. Vangelatos, N. Gottel, A. Osculati, S. Visona, S.J. Finley, et al., Effects of Extended Postmortem Interval on Microbial Communities in Organs of the Human Cadaver, Front Microbiol 11 (2020) 569630, https://doi.org/10.3389/fmicb.2020.569630.

[12] J.L. Metcalf, Estimating the postmortem interval using microbes: Knowledge gaps and a path to technology adoption, Forensic Sci. Int Genet 38 (2019) 211–218, https://doi.org/10.1016/j.fsigen.2018.11.004.

[13] B.K. Pesko, S. Weidt, M. McLaughlin, D.J. Wescott, H. Torrance, K. Burgess, et al., Postmortomics: The Potential of Untargeted Metabolomics to Highlight Markers for Time Since Death, Omics J. Integr. Biol. 24 (11) (2020) 649–659, https://doi.org/10.1089/omi.2020.0084.

[14] C. Martin, F. Verheggen, Odour profile of human corpses: A review, Forensic Chem. 10 (2018) 27–36, https://doi.org/10.1016/j.forc.2018.07.002.

[15] M.T. Ferreira, E. Cunha, Can we infer post mortem interval on the basis of decomposition rate? A case from a Portuguese cemetery, :298.e1-298.e6, Forensic Sci. Int 226 (1) (2013), https://doi.org/10.1016/j.forsciint.2013.01.006.

[16] S.J. Marhoff-Beard, S.L. Forbes, H. Green, The validation of “universal” PMI methods for the estimation of time since death in temperate Australian climates, Forensic Sci. Int 291 (2018) 158–166, https://doi.org/10.1016/j.forsciint.2018.08.022.

[17] D.L. Cockle, L.S. Bell, Human decomposition and the reliability of a ‘Universal’ model for post mortem interval estimations, :136.e1-136.e9, Forensic Sci. Int 253 (2015), https://doi.org/10.1016/j.forsciint.2015.05.018.

[18] T.H. Chua, Use of Temperature Model in Estimating Postmortem Interval in Forensic Entomology, Int J. Entomol. Res 1 (1) (2013) 11–15.
[19] M.N.S. Forbes, D.A. Finaughty, K.L. Miles, V.E. Gibbon, Inaccuracy of accumulated degree day models for estimating terrestrial post-mortem intervals in Cape Town, South Africa, Forensic Sci. Int 296 (2019) 67–73, https://doi.org/10.1016/j.forsciint.2019.01.008.
[20] A. Baptista, M. Pedrosa, F. Curate, M.T. Ferreira, M.P.M. Marques, Estimation of the post-mortem interval in human bones by infrared spectroscopy, Int J. Leg. Med 136 (1) (2022) 309–317, https://doi.org/10.1007/s00414-021-02641-9.
[21] G. Falgayrac, R. Vitale, Y. Delannoy, H. Behal, G. Penel, L. Duponchel, et al., Critical aspects of Raman spectroscopy as a tool for postmortem interval estimation, Talanta 249 (2022) 123589, https://doi.org/10.1016/j.talanta.2022.123589.
[22] S.N. Jinpa, An analysis of the development and disintegration of the body from the Tibetan medical canon and the Tukdam state from the sutras and tantras [Bod kyi gso ba rig par gsungs pa'i lus chags tshul/ lus 'jig tshul/ mdo rgyud las bstan pa'i thugs dam la dpyad pa], Men-Tsee-Khang, Dharamsala, India, 2020.
[23] Padmasambhava. G. Coleman, T. Jinpa (Eds.), G. Dorje (Trans.). The Tibetan Book of the Dead: First Complete Translation, Penguin Classics, New York, 2006.
[24] Khedrup Je. [Mkhas grub rje dge legs dpal bzang]. Entryway of Faith [Rje btsun bla ma tsong kha pa chen po'i ngo mtshar rmad du byung ba'i rnam par thar pa dad pa rgya mtsho rol pa'i 'jug ngogs]. Mundgod, India: Drepung Loseling Pethub Khangtsen Education Society.
[25] Karthar Rinpoche Khenpo, Karma Chakme's Mountain Dharma, Vol. 4, KTD Publications, 2011.
[26] M. Clark, M. Worrell, J. Pless, Postmortem Changes in Soft Tissues, in: W. Haglund, M. Sorg (Eds.), Forensic Taphonomy: The Postmortem Fate of Human Remains, CRC Press, 1997.
[27] Munsell Color X-rite, Inc, Munsell Soil-Color Charts: with Genuine Munsell Color Chips. 2009 Revised Edition, Munsell Color, Grand Rapids, MI, 2022.
[28] S. Cochrane, The Munsell Color System: A scientific compromise from the world of art, Stud. Hist. Philos. Sci. Part A 47 (2014) 26–41, https://doi.org/10.1016/j.shpsa.2014.03.004.
[29] A.I. Reeder, E. Iosua, A.R. Gray, V.A. Hammond, Validity and Reliability of the Munsell Soil Color Charts for Assessing Human Skin Color, Cancer Epidemiol. Biomark. Prev. 23 (10) (2014) 2041–2047, https://doi.org/10.1158/1055-9965.EPI-14-0269.
[30] A.H. Munsell, R.B. Farnum. A Color Notation and Illustrated System Defining All Colors and Their Relations By Measured Scales of Hue Value and Chroma, 10th edition, Munsell Color Company, Inc, 1946.
[31] D. DiMaio, V.J. DiMaio, Forensic Pathology, CRC Press, 2001.
[32] M.K. Marks, J.C. Love, I.R. Dadour, Taphonomy and Time: Estimating the Postmortem Interval. Hard Evidence, Routledge, 2009.
[33] Bukeshov [Букешов] МК, Bobrov [Бобров] A.P. Forensic-legal estimation of cadaver changes of persons died in arid zone on the example of the town of Baikonur [Судебно-Медицинская оценка динаМики трупных изМенений лиц, уМерших в аридноМ клиМате, на приМере города Байконур]. Probl Expert Med ПроблеМы Экспертизы В Медицине 2007;7(26–2):18–21.
[34] A.A. Tenkov, Establishing the prescription of death in the late pathoanatomical period, Russian Rep. Center of Forensic Medical Examination, Moscow, Russia, 2004.
[35] H. Gill-King, Chemical and Ultrastructural Aspects of Decomposition, in: W. Haglund, M. Sorg (Eds.), Forensic Taphonomy, CRC Press, 1996.
[36] M.C. Peel, B.L. Finlayson, T.A. McMahon, Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci. 11 (5) (2007) 1633–1644, https://doi.org/10.5194/hess-11-1633-2007.
[37] B. Bourel, V. Hédouin, L. Martin-Bouyer, A. Bécart, G. Tournel, M. Deveaux, et al., Effects of morphine in decomposing bodies on the development of Lucilia sericata (Diptera: Calliphoridae), J. Forensic Sci. 44 (2) (1999) 354–358.
[38] National Institute of Justice (NIJ), The Impact of Drugs on Human Decomposition and the Postmortem Interval: Insect, Scavenger and Microbial Evidence, University of Tennessee, Knoxville, TN, 2018.
[39] S.B. Giles, E. David, M.-G. Nicholas, Decomposition variability between the scene and autopsy examination and implications for post-mortem interval estimations, J. Forensic Leg. Med 85 (2022) 102292, https://doi.org/10.1016/j.jflm.2021.102292.
[40] M.H. Sorg, W.D. Haglund. Forensic Taphonomy: The Postmortem Fate of Human Remains, 1st edition, CRC Press, Boca Raton, 1997 (editors).
[41] H.L. Mickleburgh, D.J. Wescott, S. Gluschitz, M.V. Klinkenberg, Exploring the Use of Actualistic Forensic Taphonomy in the Study of (Forensic) Archaeological Human Burials: An actualistic experimental research programme at the Forensic Anthropology Center at Texas State University (FACTS), San Marcos, Texas. The Routledge Handbook of Archaeothanatology, Routledge, 2022.
[42] P. Cross, T. Simmons, The Influence of Penetrative Trauma on the Rate of Decomposition, J. Forensic Sci. 55 (2) (2010) 295–301, https://doi.org/10.1111/j.1556-4029.2009.01277.x.
[43] J. Strack, M.J. Smith, Predicted changes to the rate of human decomposition due to climate change during the 21st century, Forensic Sci. Int Rep. 7 (2023) 100321, https://doi.org/10.1016/j.fsir.2023.100321.
[44] W.M. Bass, Outdoor decomposition rates in Tennessee, in: M.H. Sorg, W. D. Haglund (Eds.), Forensic Taphonomy: The Postmortem Fate of Human Remains, CRC Press, Boca Raton, 1997, pp. 181–186.
[45] G.R. Dabbs, M. Connor, J.A. Bytheway, Interobserver Reliability of the Total Body Score System for Quantifying Human Decomposition, J. Forensic Sci. 61 (2) (2016) 445–451, https://doi.org/10.1111/1556-4029.12962.
[46] L. Rinpoche, J. Hopkins, H.X.D. Lama, Death, Intermediate State and Rebirth in Tibetan Buddhism, Snow Lion, Ithaca, N.Y., U.S.A, 1981.
[47] K. Jeremiah, Living Buddhas: The Self-Mummified Monks of Yamagata, Japan. Illustrated edition, McFarland, Jefferson, N.C, 2010.
[48] C. Quigley, The Corpse: A History. Illustrated edition, McFarland, Jefferson, N.C., 2005.
[49] J.C. Cruz, The Incorruptibles: A Study of the Incorruption of the Bodies of Various Catholic Saints and Beati. Copyright 1977 edition, Tan Books, Rockford, Ill, 1977.
[50] N. McBride, The Odour of Sanctity: When the Dead Smell Divine, The Order Good of the Death (2017;November).
[51] S.A. Harvey, Scenting Salvation: Ancient Christianity and the Olfactory Imagination. First Edition, University of California Press, Berkeley, 2006.
[52] H.T. Rowe, Paramahansa Yogananda's Mortuary Report, Forest Lawn Memorial Park, Los Angeles, CA, 1952.
[53] W. Hacke, A Collection of original voyages, EEBO Harvard University Library records - unstructured, London, 1699.
[54] C.A. Goodrich, Religious Ceremonies and Customs, or the Forms of Worship: Practiced by the Several Nations of the Known World from the Earliest Records to the Present Time, Hutchison and Dwier, Hartford, 1835.
[55] M. Tanaka, Y. Kidoh, M. Kamei, T. Terasaki, A. Watanabe, T. Sakamoto, et al., A New Instrument for Measurement of Gastrointestinal Mucosal Color, Dig. Endosc. 8 (2) (1996) 139–146, https://doi.org/10.1111/j.1443-1661.1996.tb00430.x.