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PAPER

ANTHROPOLOGY

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Differential Decomposition Patterns in Charred Versus Un-Charred Remains

ABSTRACT: Although researchers have examined many aspects of fire modification, the rate and pattern of decomposition in charred remains have not been studied previously. This study utilized 48 domestic pigs, divided into 24 charred (head, neck, and limbs burned to Crow–Glassman level 1 and torso to level 2) and 24 un-charred pig carcasses. Decomposition of control carcasses was scored at 50 accumulated degree days (ADD) intervals, and charred carcasses were also observed and photographed at this time. A Charred Body Scale was subsequently created, and charred carcasses were scored retrospectively for the same ADD intervals. Analysis using a mixed-effect repeated measures model indicated that, while decomposition rate was not statistically different between the two groups ($p = 0.2692$), the charred remains initially displayed an ostensibly more advanced pattern. Body regions displaying significant charring decomposed at a faster rate ($p < 0.001$), while areas with very light levels of charring decomposed at a significantly slower rate ($p < 0.001$).

KEYWORDS: forensic science, forensic anthropology, taphonomy, postmortem interval, accumulated degree days, burned remains

Although the number of cases encountered by forensic anthropologists may be small, fire-modified remains represent a challenge for investigators, in terms of both victim identification and the reconstruction of peri- and postmortem events. Burned and charred remains made up 6.7% of the cases the Smithsonian examined for the Federal Bureau of Investigation between 1962 and 1994 (1) and 3.2% of the cases between 1995 and 2007 (Finn CL, personal communication, 2008). The rising involvement of forensic anthropologists in disaster victim recovery and identification (2) has also meant that understanding all aspects of the fire modification of human remains is more crucial than ever before. The aim of this study was to determine whether rate and pattern of decomposition are affected by fire modification. It was hypothesized that fire modification would both alter the pattern and accelerate the rate of decomposition.

Current literature regarding the effects of fire on human remains is focused on extremes. The early stages of fire modification of human remains are well defined (3–8), as are cremation and incomplete burns resulting in calcination of bone. Previous experimental research into burned remains has examined destruction of the body in relation to intensity and duration of fire (3), as well as fat consumption and combustion (9,10). Decomposition in charred remains has not been experimentally examined previously, though it can be argued that areas of anthropological investigation could benefit from such research.

Postmortem burning of remains as a means of destroying physical evidence has been documented in various areas of forensic literature (5,11–13). Understanding the effect burning has on the pattern and rate of decomposition is crucial in establishing an accurate postmortem interval. It is currently unknown whether traditional means of postmortem interval estimation may be applied to fire-modified remains. Thus, identification of the specific pattern and rate of decomposition in charred remains would be useful for forensic investigators in terms of both planning recovery efforts and the reconstruction of peri- and postmortem events.

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Terminology

Factors involved in the combustion and sustainability of a fire, including ventilation, fire temperature, available fuel sources, and porous wicks, are varied and do not remain static throughout the course of a fire (13). As such, no two fires are the same, and, by extension, nor is the resulting damage to remains. Scales and gradations of fire modification have been established in the literature (14,15); however, none has explicitly delineated a vocabulary for use in the forensic context. Glassman and Crow (14) created a scale by which an investigator may approximate the level/degree of fire damage to remains. The Crow–Glassman Scale (CGS) represents a continuum between charring, burning, and calcination, with level descriptions that are dependent upon previous or subsequent level characteristics. This creates a level of subjectivity, which can make forensic analysis, and the collaboration of forensic investigators, more difficult. It is therefore necessary to use terminology that eliminates, or greatly limits, the subjectivity leading to inter-observer variation. For this reason, specific terminology for fire-modified remains is defined and used in this paper.

Additionally, the research presented in this paper relies heavily on the concept of accumulated degree days (ADD). ADD is defined as the sum of the average daily temperatures from the time of death until the discovery of the body. It is essentially a combined measure of time and temperature. In this paper, ADD was calculated by averaging the ambient temperature, recorded every hour, and combining each day's ADD with those of the previous days. Thus, a running ADD total was kept during the experiment.

Materials and Methods

A total of 48 pig (*Sus scrofa*) carcasses were utilized in this study. Carcasses were designated as either experimental (n = 24) or control (n = 24) and were weighed (to the nearest mg) using a rope attached to a Keenett© hanging scale. Once weighed, all carcasses were stabbed for the purposes of another research project (16). Stabbing occurred four to five times in the thorax using a guillotine affixed to a single-bladed kitchen knife. Stabs varied from dermal wounds to penetrative bone trauma. Penetrating trauma has been shown to have no effect on the rate of decomposition (17); thus, as both the experimental and the control groups received the same treatment, the stab wounds were not a factor relevant to this study.

Experimental carcasses were burned at the Washington Hall Fire Training Facility in Chorley, U.K., on a noncombustible floor (cement), so that fire modification would be limited to one-half of the body (the left side). In situations of burned remains, it is common to have an unburned region of a body, which is dependent upon the resting position of the individual and the combustibility of the substrate. Burning was concentrated on one-half of the carcasses to approximate this phenomenon. A blow torch was used to effect the charring as the flame could be controlled in compliance with health and safety requirements. Single-side burning could result in less attraction of flies and fewer attractive regions for oviposition; however, it was chosen as representing a more realistic scenario for burned remains. The individuals were charred under the supervision of a fire technician using a propane blow torch and were burned continuously for approximately 10–15 min. Heavier individuals required additional exposure to reach a level of char which approximated the smaller individuals, the maximum time of exposure being 18 min. Once the carcasses were charred, extra fire exposure was concentrated on the torsos of the carcasses to achieve differential levels of charring (head, neck, and limbs received CGS level 1 burning and torsos received CGS level 2 burning). Recorded fire temperatures, attained via a high temperature thermocouple, ranged between 985°C and 1070°C.

At the TRACES (Taphonomic Research in Anthropology: Centre for Experimental Studies) facility (18) owned by the University of Central Lancashire, carcasses were randomly distributed to avoid any slight regional differences related to location. The carcasses were enclosed in wire netting and secured to the ground to protect them from scavenging animals. As avian and rodent scavenging became an issue in the experimental group, these charred carcasses were enclosed in an additional wire cage to prevent further scavenger-related damage.

Sixteen carcasses per group (both control and experimental) were fitted with type K thermocouples, inserted rectally, to record point data on internal temperature. Two carcasses per group had temperatures measured rectally using a probe thermometer. The remaining six individuals of each group had a Lascar Electronics© self-contained thermocouple/data logger (Lascar Electronics Ltd., Salisbury, U.K.) inserted rectally to record internal temperatures at 1 h intervals continuously throughout the study. A further data logger of this type remained with the carcasses throughout and recorded ground-level ambient temperatures. These temperature data were used in all subsequent analyses. However, to time data collection intervals, ADD was approximated throughout the study using the local weather station (1.9 miles away) data. Maximum and minimum temperatures for each day were averaged and then added to the previous days' averages to create a running ADD total. Thus, data were collected approximately every 50 ADD.

Decomposition Data Collection

Notes concerning carcass appearance were taken every 50 ADD on both control and experimental groups, with special attention given to each of the three body regions (head/neck, torso, and limbs) outlined in the study of Megyesi et al. (19). Arthropod presence and activity was also noted, and photographs were taken of each carcass at each data collection point to later aid in establishing body scores.

At 100 ADD intervals, a cohort of three pigs per group was discarded from further observations so that weight and soil pH could be taken. It has been shown that repeated physical disturbance inversely affects both internal temperature and weight loss (20) and would potentially skew the data if not excluded. At the time of exclusion, each of the three pigs per group were weighed using a Keenett© scale suspended from a metal frame, by attaching chains to the four wire corners of their chicken wire cage. The combined weight of the netting and the chains was subtracted from all final weight measurements.

Internal temperature point readings were taken every 50 ADD on carcasses fitted with type K thermocouples, using a thermocouple reader. Internal temperature data collection ceased on individuals once they were excluded from the study. Internal temperatures for two carcasses from each group were obtained using a handheld probe, inserted rectally. Point data were not collected for carcasses fitted with self-contained data loggers. When advanced stages of decomposition were reached, exposure of self-contained data loggers occurred in some of the carcasses in both the control and experimental groups. Those data loggers that became exposed were allowed to remain to record ambient temperatures until the exclusion of the individual or the completion of the study, so as to maintain an equal number of point measurements for all data logger carcasses.

Initial soil samples were taken at random intervals in the area of the study; preliminary readings at the site ranged from pH 5.15 to pH 6.45. Soil pH was tested every 100 ADD from beneath the cohort of three pigs in each group that were hence excluded from observation. Soil samples were mixed in a 1:2.5 solution with distilled water and allowed to settle for approximately 10 min, after which time they were strained through muslin. pH was checked using a pH Checker (Hanna Instruments Ltd., Bedfordshire, U.K.), which was calibrated using buffer solutions prior to each laboratory session.

Creation of the Charred Body Scale

Qualitative observations of the experimental carcasses, taken at 50 ADD intervals, were compiled for each body region (head/neck, torso, and limbs). For each region, instances in which particular characteristics were noted repeatedly were tallied by ADD and converted into a percentage. Final tallies at each experimental exclusion interval demonstrated a concordance of significant terminology describing obvious progressions, revealing their correlation with specific ADD intervals. Thus, a scale for each body region could be created using specific hallmarks (characteristics that do not occur before a specific ADD) and the succession of characteristics indicated through the tallying system. Progressive point values were assigned to each stage of the scale with more advanced indicators of decomposition receiving higher point values.

Total Body Scoring

Total body scoring was carried out for control and experimental groups at each 50 ADD interval for which qualitative assessments were made. As detailed earlier for other variables, body scoring ceased on carcasses as they were excluded at 100 ADD intervals. Both contemporaneous qualitative observations and a subsequent review of photographs were used to establish the body scores.

Using the Charred Body Scale (CBS), heads and necks, torsos, and limbs were scored separately to obtain regional body scores. Under the CBS, the head and neck region is scored out of 11 points (Table 1), the torso region out of 12 (Table 2), and the limbs out of nine possible points (Table 3). Scores for each region were then combined to obtain the total charred body score, the minimum possible score being three and the maximum 32.

Control carcasses were scored using Megyesi et al.'s (19) total body scoring system. Scores were assigned, as in the experimental group, to the head/neck, torso, and limb regions at 50 ADD intervals. All scores were then combined to establish a total body score (TBS), with the lowest possible score being three and the maximum being 35. A summary of the scoring scales is given in Table 4.

Statistical Analysis

For each area of the body, scoring scales (Table 4) were standardized by converting the charred scores to the same numerical range as the un-charred scores. This was achieved using the following formula:

$$S_U = (S_C - Min_C) \times \left(\frac{Range_U}{Range_C}\right) + Min_U$$

where S = score, Min = minimum value, $Range$ = maximum − minimum, and subscripts C and U refer to charred and un-charred scales, respectively.

Differences between the decomposition rates of the un-charred and charred remains were investigated using a mixed-effects model allowing for repeated measures using the statistical software R (21) with the nlme package (22). Repeated measures analyses take into account the fact that differences between individuals as a result of natural variation will persist when these individuals are repeatedly observed. This makes for a more powerful analysis than analysis of covariance, although both will produce similar regression equations for the treatment groups.

For comparison of weight loss, an analysis of covariance (ANCOVA) model was used. However, variance was nonuniform across the range of ADDs, so a weighted least-squares model was used to compensate for this.

Results

Quantitative Data Analysis

Figure 1 shows the mean body scores by treatment type. Charred carcasses showed a more advanced stage of decomposition from *c.* 50 ADD and after around 400 ADD, though from about 300 to 380 ADD, the level of decomposition was similar between treatments. Both carcass types are approximated by curves with slopes approaching zero for higher values of ADD. This meant some form of data transformation was necessary for the mixed-effects model to fit, and a square root transformation proved most satisfactory. ADD values of between 1 and 500 were used, the lower limit to remove ADD = 0 values, which all had the same starting score, and the upper limit to remove the leveling off of the data. A random slope, random intercept model was found to be a better fit of the data. The rates of decomposition for the two treatments were not significantly different ($t = 0.825$, $p = 0.41$, d.f. = 367), allowing a simpler model to be fit omitting the interaction between $\sqrt{ADD}$ and treatment. This showed a significant difference between the intercepts of the parallel slopes ($t = 7.88$, $p < 0.001$, d.f. = 46), with the charred pigs scoring a mean of 1.87 higher than the control carcasses (Fig. 2). Thus, it appears that charring quickly resulted in a more advanced appearance of decomposition than the control pigs, but subsequently, it continued at a similar rate in both groups.

Observations suggested that different areas of the carcasses decomposed at different rates, so this was investigated quantitatively. Again, the square root of ADD was used to produce a straight line relationship in each case. The charred remains decomposed at a significantly slower rate than that of the control remains for both limbs ($t = 3.34$, $p < 0.001$, d.f. = 424) and head and neck ($t = 2.28$, $p < 0.001$, d.f. = 424). In contrast, charred torsos decomposed significantly more quickly than un-charred ($t = 5.27$, $p < 0.001$, d.f. = 424).

Internal temperatures peaked at approximately 350 ADD in the control group and only at 400 ADD in the experimental group. Internal ADD was calculated for both treatment groups using the mean continuous internal temperature data. The results show that

TABLE 1—*Stages of decomposition for the charred head and neck.*

Fresh	
1 point	Freshly burned appearance: taut skin, dry char, blister circles present (may have differential color within the circle)
Early-stage decomposition	
2 points	Neck bloat with taut skin facially, which appears moist, and prominent blister circles; skin appears mottled (uneven) and purging of fluids from the nose may occur
3 points	Neck bloat and blister circles retained with the addition of drying of the facial region and a mottled coloration
4 points	Neck bloat and blister circles retained with the addition of char sloughing (ears) and cracking of skin
5 points	Neck bloat and blister circles retained with a more even coloration and dry ears; green discoloration to mouth may be present.
6 points	Neck bloat and blister circles persist with a desiccated face and leathery texture to neck (neck skin may be loose or perforated in appearance)
Advanced decomposition	
7 points	Neck bloat gone and facial skin assumes a "mask" appearance (hallmark), loose desiccated/perforated neck tissue may remain, wet decomposition may persist in neck region
8 points	Skeletonization of ≤50% of skull and neck, wet decomposition may persist in neck region, "mask" may slip forward; thin black desiccated tissue may be apparent
9 points	Skeletonization of >50% of skull and neck, end of wet decomposition in neck region, "mask" may still be present as well as desiccated neck tissue
Skeletonization	
10 points	Skeletonization of >50% of skull and neck, bones appear greasy or moist
11 points	Dry bones

TABLE 2—*Stages of decomposition for the charred torso.*

Fresh	
1 point	Freshly burned appearance: taut, blister circles are prominent; char appears dry and uneven in texture
Early-stage decomposition	
2 points	Bloat with prominent blister circles and possible char aggregation
3 points	Previous characteristics retained with the addition of skin splitting and gray tissue color beneath char and marbling/green stomach discoloration
4 points	Previous characteristics retained with the addition of bubbling beneath char, deep splits in charred tissue and char/skin sloughing
5 points	Skin appears leathery and bloat is lost
Advanced decomposition	
6 points	Intestinal herniation through areas of heaviest char (hallmark), black discoloration, and desiccation of stomach skin may occur. Bloat may be retained
7 points	Previous characteristics retained with the addition of desiccation of herniated organs, opening/collapse of the chest (≤50% rib exposure) and increased maggot mass activity
8 points	Torso collapse/opening (hallmark) with increased desiccation of skin and >50% of ribs visible
Skeletonization	
9 points	Open torso with maggot mass activity causing displacement of ribs, pectoral/pelvic girdle and vertebrae ≤50% skeletonized
10 points	≤50% of torso through wet decomposition, maggot masses still active throughout torso, ≤50% pectoral/pelvic girdle and vertebrae skeletonized
11 points	>50% of torso through wet decomposition, maggot masses only active in localized regions (if at all), >50% pectoral/pelvic girdle and vertebrae skeletonized
12 points	Dry bones

TABLE 3—*Stages of decomposition for the charred limbs.*

Fresh	
1 point	Freshly burned appearance: char appears uneven and dry, limbs are taut with pugilistic posture, blister circles prominent and uneven coloration of skin
Early-stage decomposition	
2 points	Taut with pugilistic posture retained, singeing evident on edges of blister circles (prominent) and hair, char appears even in texture while skin coloration appears mottled/uneven. Peeling of epidermis may occur
3 points	Taut with potential char aggregation, splits may occur in tissue, pugilistic posture retained. Peeling of epidermis with wrinkling or sloughing may occur and blister circles may persist
4 points	Limbs appear withered (hallmark) with pugilistic posture retained, coloration appears even across >50% of surface, leathery in texture. Blister circles may be evident, but not prominent
Advanced decomposition	
5 points	Desiccation of limbs (especially the feet), skin of upper portion of the leg is leathery but without looseness of skin. Pugilistic posture is retained
6 points	Desiccation of limbs (especially the feet), skin of upper portion of the leg may be loose, leathery and perforated; limbs may be detached from torso. Pugilistic posture retained
Skeletonization	
7 points	≤50% skeletonized, limbs may be detached from torso and desiccated tissue may be adherent. Pugilistic posture retained
8 points	>50% skeletonized, may have desiccated tissue adherent
9 points	Dry bones

TABLE 4—*Ranges of available whole-body and body-portion scores for the two scales.*

Area of Body	Un-Charred Range	Charred Range
Whole body	3–35	3–32
Head and neck	1–13	1–11
Torso	1–12	1–12
Limbs	1–10	1–9

the internal ADD was 1007.6 in controls and 971.8 in the experimental group. These numbers surpass ambient ADD by an additional 259.9 ADD in the control group and 267.11 ADD in the experimental group.

The percentage weight lost for those individuals being excluded was calculated for 100 ADD intervals. Both treatment groups followed a similar weight loss pattern. The results of a weighted least-squares regression on percentage weight loss against ADD indicated no statistically significant difference in rate of loss between the treatment groups ($t = 1.70$, $p = 0.096$, d.f. = 45).

Soil pH values for the two treatment groups showed a similar pattern with ADD. From a starting pH of 5.66 ± 0.46 (1 SD), pH increased at similar rates for both treatment groups (ANCOVA: $t = 0.224$, $p = 0.824$, d.f. = 30) up until around ADD 350. For ADD values greater than 350, pH remained relatively stable (8.51 ± 0.20) with no significant difference between the groups (ANOVA: $F_{1,22} = 0.106$, $p = 0.748$).

Observational Data

As previously discussed, pattern of decomposition was noted to be distinctly different between the two groups. All carcasses of the control group showed the traditional pattern of decomposition, occurring first in the head and progressing backward toward the neck and the torso and eventually reaching the limbs. However, in the experimental group, the carcasses showed decomposition patterns associated with levels of burning. The torsos of all experimental carcasses began to decompose first, followed by the head/neck and the limbs to varying degrees. In the head and neck region, the experimental group decomposed beginning in the neck and moved forward toward the face. This, again, may be due to higher levels of charring in the neck region than in the facial region, as oviposition occurred by 150 ADD in the mouth.

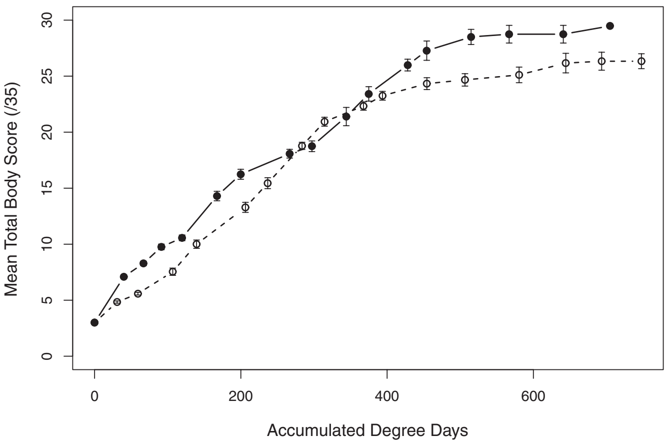

FIG. 1—*Graph showing the mean normalized total body scores for experimental and control carcasses against accumulated degree days. Closed circles and solid line represent the charred treatment group; open circles and dashed line represent the control group. Error bars show ± 1 standard deviation.*

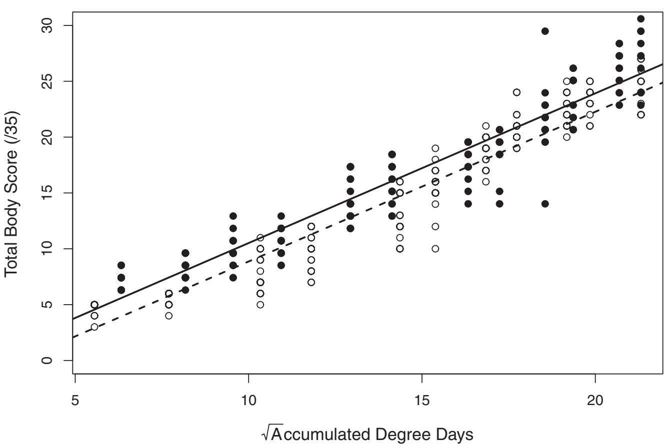

FIG. 2—*Chart demonstrating the rate of decomposition in charred and un-charred remains against the square root of accumulated degree days. Closed circles and solid line represent the charred treatment group; open circles and dashed line represent the control group.*

The experimental group also showed several unique traits in the process of decomposition. Because of the structural damage to the abdominal wall caused by heavy charring, many of the experimental carcasses exhibited intestinal herniation through the area of heaviest char. The herniation was noted from 120 ADD, while the carcasses were still retaining bloat. By 200 ADD, 65% of the carcasses remaining in the study displayed intestinal herniation. Within <150 ADD of herniation, the torso collapsed completely in all cases. Only one of the control carcasses demonstrated intestinal herniation which, unlike the experimental carcasses, occurred through the sharp force trauma in the rib region. No intestinal herniation in the experimental group occurred through the sites of penetrative trauma.

Over 344 ADD, the head and neck region in all experimental carcasses demonstrated adherent tissue with varying levels of desiccation. However, at 375 ADD, the desiccated tissue of the facial region began to loosen to take on a mask-like appearance in 83% of the experimental group. Heavy insect activity was noted beneath this mask layer at this time. In some cases (33% of experimental carcasses), the mask began to slip forward toward the snout as decomposition continued.

Experimental Site–Specific Scavenging

Circular defects in the experimental remains were noted from 66.9 ADD. These defects were approximately 7–10 mm in diameter and ranged in depth from approximately 5 to 7 mm. Edges of the defects were smooth without crenulations or irregularity. The defects were not noted in any of the control remains at any point during the course of study. Owing to the diameter of the defects and observational data, avian scavenging appears to be the source of the damage. As scavenging began prior to the presence of active maggot masses and the loss of bloat in the experimental remains, it may be inferred that the birds were not preying on larvae, but rather on the charred flesh itself.

Several experimental carcasses demonstrated large defects in the charred flesh, consistent with rodent scavenging of soft tissue (23). This type of large, shallow defect was not noted on any of the control carcasses. In one instance, a rodent identified as a field vole (*Clethrionomys glareolus*) was found trapped in the wire netting of one of the experimental carcasses.

Arthropod Activity

Arthropod activity was documented throughout data collection. Of particular interest was the presence of dung flies (*Scathophaga stercoraria*) on both the experimental and control carcasses. Even before blowflies oviposited in significant numbers, *S. stercoraria* were noted congregating on the experimental remains in the heaviest regions of charring and in trauma sites. Mating of *S. stercoraria* was noted on both the control and experimental remains. However, eggs thought to be those of *S. stercoraria* appeared to be rendered unviable owing to high temperatures, direct sunlight, and dry conditions at the time of oviposition. Larvae collected from maggot masses in both groups and reared to adulthood showed no *S. stercoraria* but did reveal the presence of *Calliphora vicina* and *Calliphora vomitoria*, which were expected, as they are known to be present at the site.

The first appearance of beetle larvae was noted at roughly the same time in both the experimental (observed at 344 ADD) and the control (at 314 ADD) carcasses. Owing to the fact that taxonomic identification is difficult to determine for larval forms, this was not attempted.

Discussion

The present study has found no difference in the rate of decomposition between charred and un-charred remains. However, because initial fire modification artificially advances the TBS by approximately three points at any given ADD when compared to un-charred remains, charred remains maintain the appearance of a body further along in the decomposition process (Fig. 3). If fire modification is suspected, allowances must be made for the initial advancement of body score. Thus, if circumstantial evidence at the scene indicates fire modification, the CBS should be applied as a more suitable alternative to the traditional Total Body Scale created by Megyesi et al. (19).

Although the overall rate of decomposition was the same in both charred and un-charred remains, decomposition rates were significantly different in the different body regions. The head/neck and limb regions of the fire modified carcasses showed a slower rate of decomposition than those of un-charred carcasses. In contrast,

FIG. 3—*Comparison of un-charred (left) and charred (right) remains at 454 accumulated degree days.*

torsos of the charred remains showed an enhanced rate of decomposition compared to torsos of un-charred carcasses. It is likely that this is attributable to the level of burning each region sustained. Heads and necks, as well as limbs, sustained CGS level 1 burning, which essentially dehydrated the outermost layers of tissue. The heaviest charred area of the carcasses, the torso, sustained CGS level 2 burning, which exposed underlying muscle tissue and created fluid seepage from cracks and trauma sites. As was noted in the study of Anderson (24), it is possible that arthropods are preferentially attracted to heavier charring where fluids and scents are released from the carcass, which would undoubtedly increase the rate of decomposition regionally. The present study indicates that areas of heavy char decompose at a faster rate than lesser-charred regions, which should be taken under consideration when investigating fire-modified remains. Further research should be conducted to determine whether regional decomposition rates may be shifted when other regions of the body sustain heaviest charring. The following equation for the regression line of the experimental group has been constructed:

$$\text{Charred Body Score} = -2.206 + 1.286 \times \sqrt{\text{ADD}}$$

The standard error associated with the regression coefficient is 0.024, giving a t-value of 53.723 and a p-value of 0.000 for the null hypothesis that the coefficient is not different to zero. It is not possible to give a constant quantity that would accurately quantify the error associated with a prediction for any value of ADD, despite prior studies having implied otherwise (19). The prediction interval varies for different values of ADD, being smallest at the mean of ADD and increasing with greater divergence from it (25). Investigators should be cautious in the use of predictive equations, especially if the goal is to predict what was an explanatory variable based upon what was a response variable in the original experiment (e.g., ADD from TBS).

Specific traits and character suites occurred at predictable times, and patterns of onset and offset emerged throughout the decomposition of charred remains. During the early stages of decomposition in the head/neck region, neck bloat was often accompanied by desiccation of the face and a leathery quality of skin of the neck region. As decomposition progressed in the head/neck region of charred remains, a mask of desiccated loose tissue formed at the face and was accompanied by loose or perforated neck tissue (owing to arthropod activity), which remained during wet decomposition.

In the torsos of the charred remains, specific traits were associated with specific points in time and have formed hallmarks of certain stages of decomposition. Of the charred carcasses, 65% displayed intestinal herniation (in the area of heaviest char) during their decompositional trajectory (Fig. 4). Intestinal herniation was first noted at 120 ADD and peaked between 200 and 267 ADD. It was also noted that herniation occurred within approximately 150 ADD following the loss of bloat, with the chest cavity noted as opening no earlier than 200 ADD and the abdominal cavity noted as opening no earlier than 267 ADD. Owing to the close association between herniation and chest and abdominal collapse, intestinal herniation has been deemed the most reliable hallmark of the end of the bloat phase in charred remains in this study. Skeletonization of more than 50% of the torso was noted to occur no earlier than 428 ADD, reaching regional skeletonization in 100% of the group by 705 ADD.

Charred limbs produced the most consistent and predictable pattern of decomposition in the charred carcasses. Initial taut skin gave way to withered and dehydrated-looking limbs no earlier than 167 ADD. Withered limbs were maintained until the first bones were visible at 344 ADD. Decomposition in the limbs typically progressed from the femur (or humerus) downward toward the foot. There were no cases in the experimental group in which bones of the feet were exposed; 100% of the group exhibited desiccation of the feet by 454 ADD.

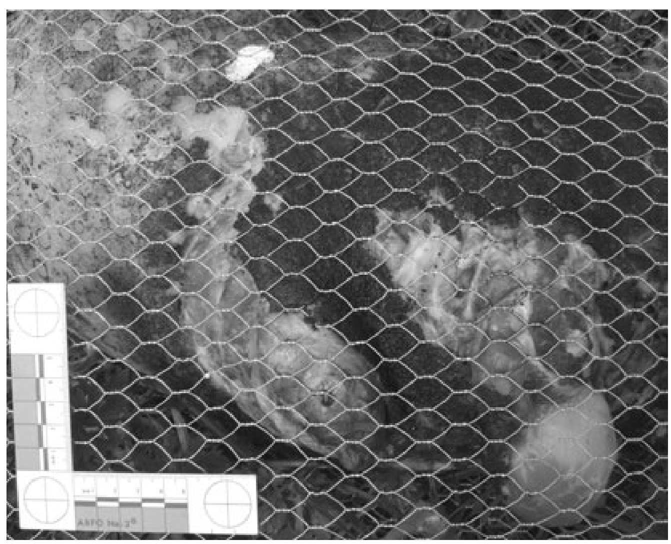

FIG. 4—*Intestinal herniation in the area of heaviest char, at 167 accumulated degree days.*

Experimental carcasses displayed circular defects, with a diameter of approximately 10 mm, which have been attributed to avian scavenging. Bass (26) stated that avian attraction to remains was based on the presence of maggots, and scavenging-related defects in soft tissue were merely an artifact of larval predation. However, Komar (27) found that birds were actively scavenging decomposing flesh rather than focusing solely on maggots. This was found to be the case in the present study, as avian scavenging occurred prior to the presence of maggot masses and was not seen in un-charred remains when maggot masses became active. Jackdaws (*Corvus monedula*) were observed perched on the wire mesh above the charred remains at numerous times during the early decomposition phase. A preference for charred over un-charred remains has not been documented previously in the literature and should be investigated further.

The present study encountered several limitations that should be addressed in future research. Although pig skin thickness, diet/digestive tract, and bone thickness are similar to those of humans (28) and we are confident that the decomposition observations presented here for pigs (*S. scrofa*) are applicable to humans, we must still be somewhat cautious in applying the decomposition rate equations derived from pigs to human remains owing to carcass size differences (29).

Regional rate and pattern of decomposition were noted to be different in the charred group when compared to the un-charred group. The torso of the charred remains decomposed at a faster rate than in the un-charred group, whereas the head/neck and limb regions decomposed at a slower rate than in the un-charred group. The difference in decomposition rate and pattern may be due to the level of charring in each region. Heavy charring encouraged decomposition, while the areas with light charring appeared to be retarded in the decomposition process. Subsequent studies should focus on alternating the areas of heaviest char, so that it may be determined whether region or charring level dictates the rate of decomposition.

Acknowledgments

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