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Taphonomic Changes to Blunt Force Trauma: A Preliminary Study*

Abstract: This study examines the effects of taphonomic processes on blunt force trauma (BFT) through an experimental study involving pig heads. Of particular concern is the possibility that taphonomic changes can create pseudo-trauma and/or conceal evidence of actual trauma. BFT was inflicted on 10 pig skulls using a hammer. The skulls were subsequently exposed to the environment for 12 months. Seven taphonomic changes were evaluated: the freeze–thaw cycle; rodent gnawing; carnivore scavenging; presence/weight of soil; presence/weight of rain and snow; movement/displacement of bones; and discoloration due to sun bleaching and grass staining. Taphonomic effects varied between cancellous, compact, fresh, and degreased bone. Freezing and thawing, exposure to rain and snow, movement of the skulls, and soil erosion altered and, in some cases disguised, pre-existing trauma. Rodent and carnivore activity did not obliterate evidence of BFT. Recommendations for evaluating BFT on remains affected by taphonomic processes are presented. As each taphonomic process outlined by this study has the potential to disguise antemortem injury, the authors propose that one must carefully examine large, circular openings in the skull that may represent the remnant evidence of BFT.

KEYWORDS: forensic science, forensic anthropology, blunt force trauma, taphonomy

Taphonomy is the study of processes that affect any organism from the time of death to the time of discovery (1). Taphonomic factors include both natural phenomena (environmental, floral, and faunal) and human interference. After death, taphonomic processes can alter the appearance of bone to such a degree that forensic investigators may not be able to recognize evidence of criminal activity, e.g., surface remains in fields with tall crops can be inadvertently run over by farm equipment, resulting in crushing and sharp force trauma that may mask preexisting intentionally inflicted wounds. Documenting and experimenting with taphonomic variables assists forensic investigators to interpret accurately the damage inflicted to bone, in particular, to distinguish antemortem trauma from postmortem damage, and to identify taphonomic changes that have the potential to mask evidence of foul play.

The literature contains numerous articles discussing taphonomic variables that affect the character of bone, but few publications consider whether it is possible for taphonomic changes to entirely disguise antemortem trauma (1–18). The purpose of this analysis is to determine the degree to which taphonomic processes can conceal blunt force trauma (BFT) through an experimental pilot study using pig (*Sus scrofa*) heads. This objective was achieved by inflicting BFT on 10 pig skulls and exposing them to natural environmental conditions for 1 year. Seasonal variation is a significant component of taphonomic analysis. Different variables impact the remains to a greater or lesser degree, depending on the time of year and length of exposure. This research evaluates the effects of seven taphonomic factors on the impact site and fractures induced through BFT, including: (1) the freeze–thaw cycle in Southern Ontario, (2) rodent gnawing, (3) carnivore scavenging, (4) movement by scavengers and displacement of the bones, (5) soil encasement/erosion (6). the presence and weight of rain/snow, and (7) bleaching and vegetation staining. The extent of taphonomic alteration and the characteristic marks indicative of BFT were monitored at several stages of the research period and reevaluated at its conclusion.

BFT to the cranial vault can be distinguished from other forms of trauma on the basis of six modifications to the ectocranial surface: (1) inbending and initial fracture formation, (2) inward displacement of bone, (3) radiating fractures in the area of outbending that initiates at one or more points distant to the impact site, progressing both toward it and in the opposite direction, (4) concentric fractures forming perpendicular to the radiating fractures, (5) some depression at the sutures, and (6) knapping or flaking along fracture margins (19–21).

Based on blunt force fracture mechanics and documented patterns of taphonomy, three expectations were postulated: (1) by the end of the study period, approximately 12 months after exposure, taphonomic processes will obliterate all trace of radiating and concentric fractures, but the depression or inward displacement of bone will remain unaffected, providing the only evidence of preexisting trauma, (2) taphonomic changes one might expect to see along the injury margins of bone over the course of 1 year include: finely scalloped and serrated edges from scavenging, and cracking and/or flaking of bone due to weathering (2,4,5,12–15), and (3) such taphonomic changes are expected to occur in areas of the body that are exposed, unprotected, and moist, specifically the orbital, nasal, and maxillary margins (2,4,22).

Methods and Materials

Ten fresh (unfrozen) pig heads (*S. scrofa)* were obtained from animals destined for consumer use. Each head weighed approximately 12–15 pounds. Each specimen was individually numbered, labeled with a Pig Identification Number (PIN) (1–10), and tagged using wire fastened around the mandible for identification. Animals were selected as human proxies in this study for two reasons:

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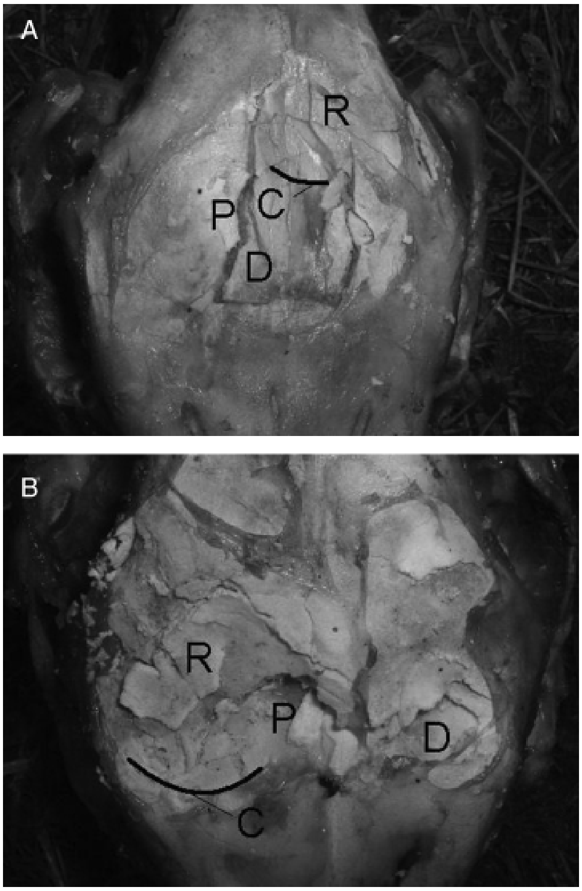

FIG. 1—*Fracture patterning. The superior views of the impact sites on the frontal/parietal bones of PIN 7 and 8 are shown here in 1A and B, respectively. Perforation (P), inward depression of bone (D), radiating (R), and concentric (C) fractures are present.*

(1) the hairless skin of the pig is similar to human skin, and (2) this research is not concerned with measuring the force necessary to damage bone. Emphasis is on postmortem changes to existing fracture patterns; thus, the density of the pig cranium relative to the human cranium was of no concern.

In typical forensic cases, bodies dumped and exposed to scavenging are not defleshed. Consequently, the flesh was retained on five of the pig heads (PIN 1–5) to convincingly reflect taphonomic and decompositional changes. Defleshed specimens permit visual identification, description, and documentation of fracture sites; thus, the flesh was removed from heads six through 10 (PIN 6–10) by careful dissection using only a scalpel and scissors.

A Genuine Hickory Benchmark hammer (size: 1030–565), a common household tool that is easily accessible, was used to inflict a number of blows on both the right and left frontal/parietal bones of each specimen with enough force to perforate the outer table of bone. This created complete fractures, some depressions, hinge fractures, radiating, and concentric fractures (Fig. 1). Multiple blows to the impact sites resulted in knapping and flaking along the fracture margins.

The investigator documented the trauma inflicted on the defleshed specimens through photographs (anterior, lateral, and superior aspects) and schematic diagrams, allowing for a detailed comparison to their appearance after exposure to taphonomic processes. A data sheet was completed for each of the defleshed specimens detailing gross morphological changes observed by the investigator. The investigator recorded the presence or absence of: (1) hinge fractures, (2) complete and continuous linear fracture formation in the area of outbending, including whether breakage initiated at one or more points distant to the impact site, progressing both toward it and in the opposite direction, (3) radiating fractures, branches, and wedge-shaped plates, and (4) concentric fractures. The width and length of fractures were measured using a spreading caliper from the impact point to the point at which the fracture line dissipated. Morphological characteristics of each impact site and subsequent fracture pattern were also documented by recording the number of lesions, bone, aspect and surface affected, and whether knapping or flaking occurred at fracture margins. See Table 1 for a complete list of the number or blows to each cranium.

It was difficult to obtain detailed photographs and diagrams of fracture patterning for the fleshed heads. Radiographic equipment was not operational and therefore, unavailable for use. The investigator could not be certain that the force applied to the cranium was enough to perforate the outer table of bone. A diagram was used to document the location of the potential fracture sites for each fleshed specimen. Changes to flesh were documented throughout the duration of this study.

The specimens were placed on the ground surface, in a low-brush area among overturned soil. The 17.2 × 10.1 m area is enclosed by chain-link wire and wooden plank fencing 2.4 m high on the east, west, and south boundaries. An abandoned barn borders the north boundary of the site. The purpose of the fence was to prevent the removal of specimens from the research area. Although no digging of soil under the fence was observed, both carnivore and rodent scavengers had access to the research area by: (1) climbing the fence to enter the site, (2) entering through small holes in both the decaying pieces of wooden fencing and walls of the barn, and (3) entering through the bottom of the chain-link fence where it was observed to curl inwards to the site. Owing to the height of the fence, carnivores were prevented from carrying the skulls to another location but had unlimited access to specimens within the enclosure. In this study, animal size was not a factor in accessing specimens. The enclosure also prevented human traffic and interference. The heads were placed on site from October 4, 2003, until September 30, 2004, 52 weeks, to allow for maximum seasonal exposure.

Changes to the skull were documented at specified intervals. Table 2 lists the timing of each site visit. During the winter months of the experiment, notable changes decreased and animal activity slowed. Once the temperature increased and animal activity intensified, the investigator modified the schedule to return to the site as necessary.

TABLE 1—*Total number of blows administered to the anterior cranial vault of PIN 1 through 10.*

# of Blows	PIN1	PIN2	PIN3	PIN4	PIN5	PIN6	PIN7	PIN8	PIN9	PIN10
R. Frontal Bone	5	3	4	2	4	4	3	5	3	2
L. Frontal Bone	3	3	2	2	3	2	3	2	3	3
Total	8	6	6	4	7	6	6	7	6	5

TABLE 2—*Site visits.*

Date	Day Number	Date	Day Number
October 5, 2003	1	January 10, 2004	98
October 6, 2003	2	February 7, 2004	126
October 7, 2003	3	February 26, 2004	145
October 8, 2003	4	March 19, 2004	168
October 9, 2003	5	April 14, 2004	193
October 10, 2003	6	May 17, 2004	207
October 11, 2003	7	June 14, 2004	226
October 13, 2003	9	July 15, 2004	254
October 22, 2003	18	July 29, 2004	285
October 29, 2003	25	August 18, 2004	299
November 6, 2003	33	September 1, 2004	333
November 22, 2003	49	September 16, 2004	348
December 21, 2003	78	September 30, 2004	362

During each site visit, a detailed data sheet was completed for each pig head. The investigator documented and recorded: where flesh or bone had been removed from the specimen; the presence of insects; the movement of the skull as of the last visit; scavenging marks; and all other evidence of damage to the bone observable at the macroscopic level.

At the completion of 52 weeks of exposure, the specimens were collected and processed in the skeletal preparation lab of the University of Toronto at Mississauga. The remaining soft tissue was removed under the fume hood using a nonbleaching method that involved soaking the specimens in heated water (never allowing the water to boil) and later rinsing (22). This procedure was followed to allow for complete visualization of fractures and taphonomic alterations, while causing the least amount of additional change to the bone. This method of removing soft tissue is a safe and simple procedure that produces high-quality specimens for analysis and documentation (22).

The trauma inflicted on each specimen was re-examined and the effects of taphonomic processes were analyzed using the dissecting microscope, detailed photographs, and secondary observers to verify hypotheses. Graduate students in forensic anthropology at the University of Toronto examined the affected specimens for macroscopic evidence of BFT. The students were completely unbiased in their assessment, as they had no knowledge of previous trauma inflicted on the cranium. The students were asked to detect the presence/absence of: (1) inward displacement of bone, (2) radiating fractures, (3) concentric fractures, and (4) any other markings indicative of BFT.

Results

Taphonomic effects were correlated with both environmental observations and changes to bone structure. Tables 3 and 4 summarize the effects of seven taphonomic factors with potential to disguise evidence of BFT on PIN 1–10 from Days 1 to 362. For clarity, the seven taphonomic factors observed in this study will be discussed independently, but it must be noted that they are, in fact, interdependent.

TABLE 3—*Summary of taphonomic changes due to the effects of the natural environment as seen by the investigator from Days 1 to 362.*

	Freeze–Thaw Cycle	Soil Protection/Erosion	Displacement from Rain/Snow	Bleaching/Vegetation Staining
Fleshed				
PIN 1	Flaking, wedging present on anterior surface of right mandibular ramus, not caused by BFT	No reaction found	No displacement of bone at the impact site(s)	No reaction found
PIN 2	Continuous linear cracking on anterior aspect of left frontal bone, originating at coronal suture, is disguised as BFT	No reaction found	No displacement of bone at the impact site(s)	Soil staining present on cranial vault, highlighting evidence of weathering
PIN 3	Flaking, wedging present on anterior surface of right mandibular ramus. Right-angled cracking on frontal bone, originating at coronal suture, is disguised as BFT.	No reaction found	Inward displacement of fracture on right frontal bone, caused by weight of precipitation	Soil staining present on mandible
PIN 4	No reaction found	No reaction found	No displacement of bone at the impact site(s)	Soil staining present on mandible
PIN 5	No reaction found	No reaction found	No displacement of bone at the impact site(s)	No reaction found
Defleshed				
PIN 6	Extreme cracking, flaking, wedging of bone found on cranial vault, originating at saggital and coronal suture, not caused by BFT. Evidence of BFT is obliterated at impact site(s)	No reaction found	Complete displacement of fractured bone at the right frontal impact site, due to weight of precipitation	Extreme contrast of bleaching, vegetation staining on skull, highlighting impact site(s)
PIN 7	No reaction found	No reaction found	No displacement of bone at the impact site(s)	Extreme contrast of bleaching, vegetation staining on cranial vault, highlighting impact site(s)
PIN 8	No reaction found	No reaction found	No displacement of bone at the impact site(s)	Extreme contrast of bleaching, vegetation staining on cranial vault, highlighting impact site(s)
PIN 9	Cracking, flaking, wedging of bone found high on cranial vault on both right and left parietal bones. These did not influence the impact site(s)	Completely encased in soil from Day 48–362. Soil erosion obliterated evidence of BFT	No displacement of bone at the impact site(s)	Soil encasing protected cranial bones from loss of moisture. Bone appears fresh, staining from soil is present
PIN 10	Extreme cracking, flaking, wedging of bone found on cranial vault, originating at saggital and coronal suture, not caused by BFT. Evidence of BFT is obliterated at impact site(s)	No reaction found	Inward displacement of fractures found on cranial vault, caused by weight of precipitation	Extreme contrast of bleaching, vegetation staining on the skull, highlighting impact site(s)

BFT, blunt force trauma.

TABLE 4—*Summary of taphonomic changes due to the effects of animal activity as seen by the investigator from Day 1 through to Day 362.*

	Approx. # of Meters (m) Moved	Movement from Animal Activity	Rodent Gnawing	Carnivore Scavenging
Fleshed				
PIN 1	5.86	No displacement of bone at the impact site(s)	None	Dental scoring and claw marks found on mandible; these did not affect impact site(s)
PIN 2	6.71	No displacement of bone at the impact site(s)	None	None
PIN 3	18.6	No displacement of bone at the impact site(s)	None	Claw marks on occiptal bone and superior surface of right mandible; these did not affect impact site(s)
PIN 4	35.1	Severe damage, resulting in complete removal of right temporal bone and separation of sutures	None	Dental scoring and claw marks on right nasal margin and maxilla; these did not affect impact site(s)
PIN 5	12.2	No displacement of bone at the impact site(s)	None	Puncture marks in soft tissue; claw marks on mandible and cervical vertebra
Defleshed				
PIN 6	8.5	No displacement of bone at the impact site(s)	None	None
PIN 7	6.1	Moderate damage at the impact sites, slight inward displacement of frontal and parietal bones	None	Dental scoring not limited to one specific area of skull; claw marks on right nasal margin
PIN 8	7.0	Moderate damage at the impact sites, slight inward displacement of frontal and parietal bones	None	Dental scoring not limited to one specific area of skull; puncture marks on premaxilla and cervical vertebra
PIN 9	8.8	No displacement of bone at the impact site(s)	None	Dental scoring not limited to one specific area of skull; right inferior orbital margin removed
PIN 10	1.8	No displacement of bone at the impact site(s)	None	None

BFT, blunt force trauma.

Freeze–Thaw Cycle of Southern Ontario

The effects of the freeze–thaw cycle showed the most potential to disguise evidence of BFT. Cracking, flaking, and wedging of bone altered the impact sites of the defleshed specimens, completely obliterating evidence of BFT (Fig. 2). The freeze–thaw cycle also created roughly linear fractures on the frontal bone, originating at the suture, and on the mandible, mimicking antemortem injuries (Fig. 3). Secondary observers in this study were persuaded that BFT had been inflicted on these areas. None of the cranial bones exhibited warping as a result of freezing and thawing.

In the frozen environment, the rate of decomposition slowed to almost zero and the types of taphonomic changes altered substantially compared with warm weather effects, as has been demonstrated in other studies (12,15). Soft tissue is preserved in the frozen state, during which time bacterial growth ceases (15). As soil freezes from the ground surface downward, freezing causes crystalline water molecules in soil to expand significantly more than ordinary surface evaporation of soil water (15). This process explains the unusual fracture line distribution seen on the right frontal bones of PIN 3 and 10, originating at the coronal sutures (Figs. 2*B* and 3*B*). These skulls were positioned with their frontals in contact with the soil. The fractures suggest that the investigator penetrated the bone by blunt force, but weathering has affected the impact site, creating post-mortem cracking (pseudo-trauma) and extreme flaking that both disguised existing radiating fractures and also mimicked BFT by creating additional linear fractures.

The defleshed specimens exhibited complete obliteration of BFT at the impact sites, while the fleshed specimens manifested this characteristic to a lesser degree. The difference between the fleshed and defleshed specimens is likely due to the slow decomposition rate of the flesh itself, typically observed in cold climate studies (12,15). There was little evidence of decomposition of the outer layer of skin on four of the five fleshed specimens before Day 133. Flaking and wedging of bone at the impact sites were not as severe on the fleshed specimens. In contrast, the exposed bone, devoid of flesh, quickly became dry and brittle. Although flat bones of the human skull, such as the parietal and temporal bone, may warp due to humidity and fluctuation in temperature, these bones of the pig are extremely dense and seemingly impervious to this reaction (13,15,18).

Effects of Rain and Snow

Bone exposed to environmental stress over any period of time becomes dry, grainy, light in weight, fragile, discolored, and stripped of soft tissue (21). Exposure to air causes loss of moisture, resulting in various degrees of dehydrated, brittle bone (21). Bones vulnerable to the effects of rain and snow are also susceptible to cracking, wedging, and flaking, which can either mimic or disguise BFT. Such changes were observed in PIN 6 and 10 (Figs. 2 and 4).

A total of 177.83 cm of precipitation fell in the 362 days of this experiment. Exposure to precipitation over an extended period of time causes inward displacement of bone at the impact site, leaving only the border of the outermost concentric fracture intact. The accumulated rain and snow caused complete displacement of fractured bone in PIN 6, where portions of the right frontal bone at the impact site are completely displaced (Fig. 4). The effects of rain and snow changed the character of bone considerably, creating fractures originating at the sagittal and coronal sutures (Figs. 2 and 4).

PIN 6 and 10 were exposed to precipitation for the duration of this study. This explains why the weight of rain and snow showed the most damage to the impact sites on the defleshed heads. All the remaining specimens were protected by an overhead covering, left from an abandoned shack within the enclosed perimeter, for more than 312 days of the experiment. As the defleshed specimens were exposed to rain and snow for a minimal amount of time, the weight of precipitation had little effect on the displacement of bones.

Effects of Animal Activity

Movement of the crania by animals is a significant factor in post-mortem alteration of BFT. In an effort to store food, the raccoon and coyote bury their finds and may remove bones from the area (8). Raccoon footprints were observed at the site. To prevent

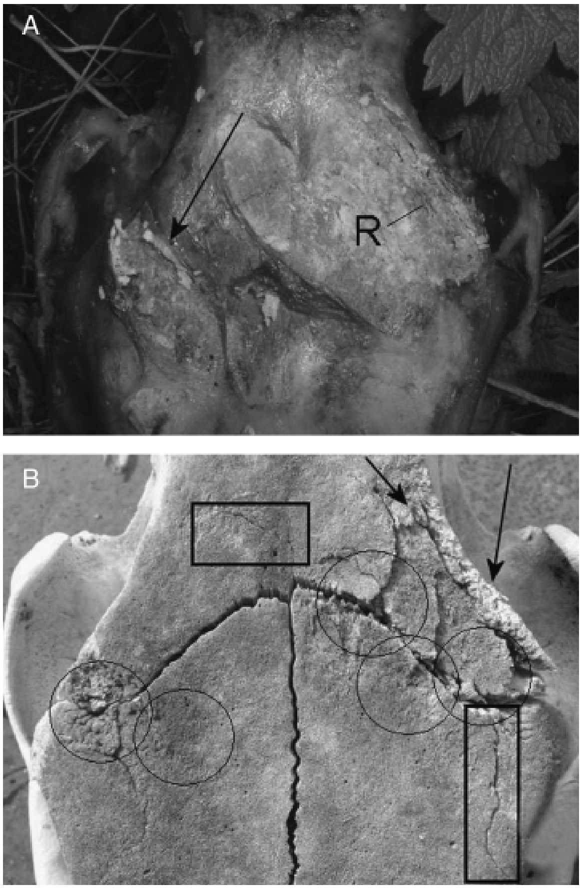

FIG. 2—*Effects of weathering. PIN 10 on Day 5 and 347 are shown here in 2A and B, respectively. In 2A, bone was not penetrated by BFT but resulted in knapping, which circumscribed the impact sites, and radiating fractures. In 2B, deep cracking, wedging and flaking of bone, the result of exposure to environmental stress, are found surrounding the impact sites, disguising evidence of radiating and hinge fracture. In addition to this, the texture of the outer table of bone appears blistered. The effects of the freeze–thaw cycle and exposure to rain/snow also created additional radiating fractures, not associated with BFT, originating at the coronal and sagittal sutures. These are denoted by boxes in 2B.*

loss of experimental specimens, a well-monitored and secured enclosure is vital. In this experiment, movement of the skulls, within the enclosure, by carnivorous animals resulted in extensive damage to the cranial bones, including increased separation of suture lines (Fig. 5). The degree of separation of sutures is not related to the effects of BFT. Prolonged exposure to scavenging and precipitation magnified the degree of inward depression and displacement of bone at impact sites (8,18).

Trauma to the skull of PIN 4 (Fig. 5*A*) resulted in merely a separation of sutures and not a fracture. Displacement of the sutures and temporal bone caused by carnivore scavenging and movement of the pig head decreased the observer's ability to recognize evidence of trauma. The right parietal bone is separated along its sutures, although no other sign of BFT is present: the edges of bone along the suture are not damaged; fragile bones of the skull remain intact; and the affected bone does not lie depressed below the plane of adjacent bones. The right temporal bone of PIN 4 has been completely removed (Fig. 5*A*). Had BFT been inflicted on this area, evidence of it would have been lost due to animal activity. Displacement of this bone is the result of movement by scavengers; this specimen was transported a total of 35.1 m over 362 days.

PIN 8 suffered moderate depression at the impact sites resulting from inward displacement of the frontal and parietal bones through movement of the specimens by animal activity. The edges of these bones are damaged and both lie depressed beneath the plane of adjacent bones. Evidence of BFT has not been destroyed; radiating and concentric fractures are present (Fig. 5*B*).

The fleshed specimens suffered more damage to the cranial bones from movement by animal activity than was seen in the defleshed heads, likely because the former provided a source of food for the animals. The defleshed specimens were moved a combined total of 32.2 m by animal activity. The fleshed heads were moved a combined total of 78.5 m, which explains the greater degree of damage observed at the impact sites of the fleshed heads.

According to the literature, crania exposed to trauma, specifically that of blunt force, are more subject to destruction from both rodent and carnivore scavenging (2–7,16). The amount of damage rodents and carnivores can produce is ultimately dependent upon tooth morphology, jaw mechanics, and strength relative to bone (2–7). Dental scoring found along the margins of the nasal aperature and perforations of the thin bones of the maxillae are consistent with Haglund's findings (5). The location and frequency of distinct claw marks, indentations, and puncture marks found on the bone help the investigator to understand how movement of the specimens by animal activity contributed to the damage at impact sites. Observed claw markings are evenly distributed in three parallel rows; longer than they are wide; and too thin in diameter and cross-section to be mistaken for teeth markings.

In this study, the location and angle of discernible claw marks, found on the dorsal aspect of the atlas and lateral surface of the mandibular ramus, suggest that carnivorous scavengers attempted to lift/grab the specimens. On Day 49, the investigator found the fleshed specimens gathered together in one location; behind a board leaning against a wall. The movement of skeletal elements can affect access to the bones by other scavengers. PIN 7–9 exhibit extensive dental scoring, not limited to one specific area of the skull. Although none of the damage caused by carnivore scavenging obliterated trauma in this study, animals do have the capacity to consume bones, to a greater or lesser degree depending on the size of the scavenger. Both fleshed and defleshed specimens exhibited similar marks made by canid scavenging.

The investigator expected to observe rodent gnawing at the edges of broken bone and exposed orifices; yet, no specific rodent markings were noted. In this study, rodent scavenging had no direct effect on BFT. Hibernation habits, gathering tactics, and distribution of rodents can be fairly predictable, and while rodents are capable of destroying bony elements, animal activity is extremely variable (2,4,7,8,16).

Bleaching, Grass, and Soil Staining

The bright green and white color of bone that is produced by contact with vegetation and exposure to sunlight is helpful to investigators in identifying macroscopic evidence of BFT on the cranium by providing contrast to highlight impact sites and fracture lines (1,20). In this study, bleaching and grass staining highlighted impact sites as well as cracking and hinge fractures, resulting from weathering of bone. No image is provided as black and white photography cannot adequately convey the effects of color change.

PIN 6 and 10 were exposed to sunlight for the duration of this study. Extreme bleaching is observed on the skull and prolonged exposure to sunlight contributed to flaking of the cortical bone.

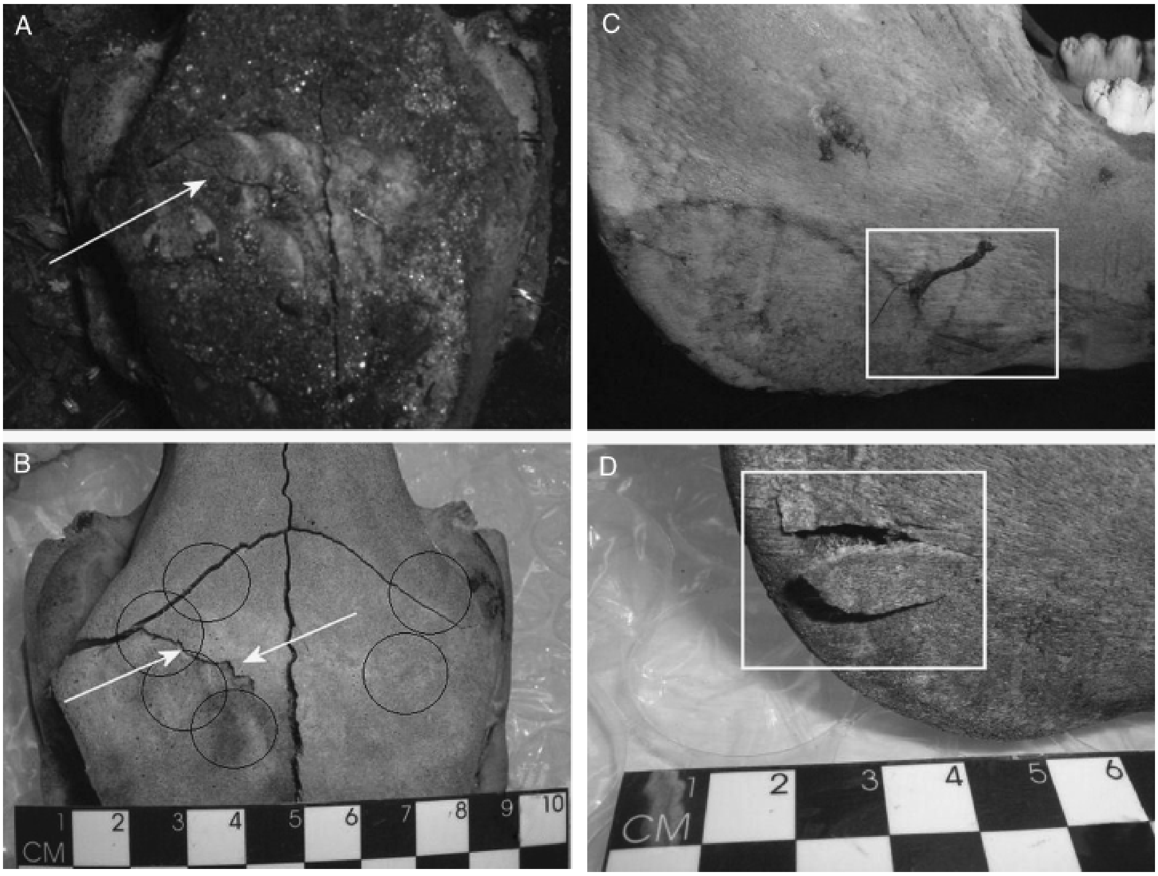

FIG. 3—*Effects of weathering. PIN 3 on Day 168 and 362 are shown here in 3A and B, respectively. Linear fracture, as illustrated by the arrow, which originates at the coronal suture on the right frontal bone, is the result of extreme weathering and can potentially be mistaken for evidence of BFT. However, the change in direction of this linear fracture, denoted by the arrows in 3B, indicates that it occurred postmortem. 3C and D show the right lateral aspect of the mandibles for PIN 1 and 3, respectively. Evidence of flaking, as illustrated by the boxes, are due to the effects of the freeze–thaw cycle and not BFT as identified by secondary observers.*

Defleshed specimens exhibited discoloration and cortical bone flaking due to exposure to sunlight over the fleshed heads. There was no difference in discoloration due to contact with vegetation between the fleshed and defleshed specimens.

Effects of Soil Protection and Erosion

The color and degree of greasiness of bone are factors used in assessing time since death (1). In this study, bones were exposed to taphonomic processes for approximately 1 year, but complete soil encrustation of PIN 9 caused the remains to maintain a fresh appearance. Although none of the specimens were buried, movement of the skulls over the muddy ground surface resulted in a thick layer of soil deposition coating the skull and filling exposed orifices. PINS 1–4 were skeletonized by Day 158 and bones were encased in soil for the remainder of the experiment, 206 days. With the exception of PIN 9, the fleshed specimens exhibited significantly greater damage due to soil erosion. Although most studies focus on the erosive effects of soil, remains encased in soil are protected from loss of moisture, scavenging, and damage to fracture line distribution.

PIN 9 was encased in soil for more than 300 days of this experiment. The presence of soil affected the cranium in two ways. First, it protected the bone. When PIN 9 was cleaned a year after BFT was inflicted, blood was still present in the bones, giving the impression that death had occurred more recently than was the case. In addition, rodent scavenging was halted at the impact site on the left frontal/parietal bone due to the thick layer of soil deposition. Soil encrustation prevented rodent scavenging and preserved fracture patterning. Prolonged weight of soil on the impact site did cause a slight inward displacement, but did not destroy evidence of BFT (Fig. 6).

Soil erosion caused loss of cortical bone at the right frontal/parietal impact site, resulting in scalloped edges and complete obliteration of evidence of BFT (Fig. 6). Experienced examiners did not identify the right frontal bone of PIN 9 as a potential site of trauma. Scalloped edges surrounding an impact site were confused for carnivore scavenging.

Blood Staining

In the event of trauma on bone, blood is leaked from veins and arteries to form a pool (hematoma) over the damaged area. Staining from the hematoma, resulting from perimortem, trauma can be seen on dried bone (20). Lacerations in the flesh of PIN 5 did little to expose evidence of trauma on the cranial vault. PIN 5 was the only specimen that did not skeletonize within 362 days. Surprisingly, an abundance of blood was found within the bone; the result from staining of the hematoma on the frontal/parietal bones was still evident after 1 year (Fig. 7). Although BFT did not penetrate the bone, evidence of foul play was not eradicated.

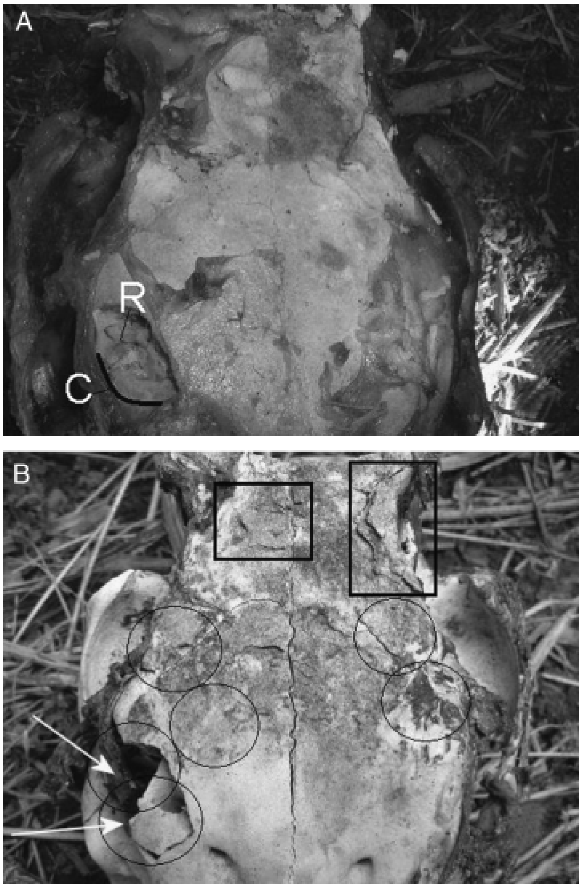

FIG. 4—*Effects of rain and snow. PIN 6 on Day 6 and 347 are shown here in 4A and B respectively. Attention is focused on the right frontal bone where complete displacement caused by exposure to rain and snow, has obliterated evidence of concentric and radiating fracture. Flaking and radiating fractures, originating at the sagittal suture, are observed on both the right and left parietal bones in 4B, denoted by the boxes.*

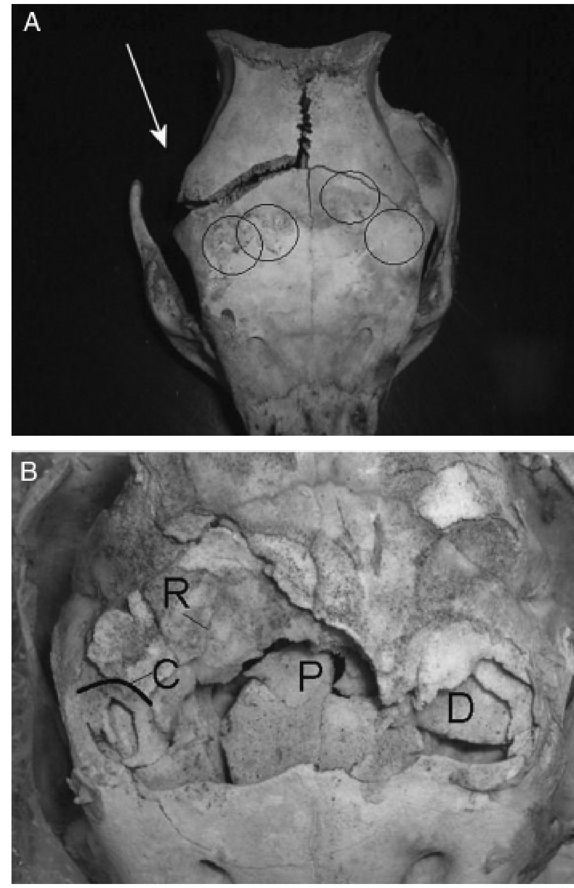

FIG. 5—*As illustrated by the arrow in 5A, the right temporal bone of PIN 4 has been completely removed. This specimen suffered extensive damage due to displacement by scavengers, including increased separation of sutures, which was, in no way related to the effects of BFT. As illustrated in 5B, evidence of perforation of bone (P), radiating (R), and concentric (C) fractures is still present in PIN 8. This specimen was transported 7.0 m in the duration of this study and exhibits moderate inward depression (D) at the impact sites. Evidence of BFT is still evident.*

Discussion and Conclusions

Temperature, moisture levels, and other environmental conditions alter the rate at which decomposition occurs, and affect the nature of postmortem changes. The results of this study demonstrate the importance of examining and documenting taphonomic changes at the microenvironmental level and by season. While several of the findings of this research are in accordance with the published literature, distinct differences in the timing and effects of taphonomic changes such as cracking and dehydration were evident.

Komar (12) and Micozzi (15) have observed that freeze–thaw cycles can accelerate the rate of disarticulation, causing the bones to move freely as independent units and increasing their susceptibility to transportation by scavengers, water, and gravity. This was the case in this experiment. As early as Day 25, the mandible of PIN 3 had detached from the skull, and cartilaginous attachments on PIN 6 and 10 had also disarticulated. The average mean temperature in October 2003 declined from 8.7° to -0.5°C in December 2003, and 29.7 cm of snow fell during these months. By Day 145, the mandibles had also detached from PIN 1, 2, and 4. The average mean temperatures in the months of January and February 2004 were -9.7° and -3.9°C respectively, well below the freezing point and cold enough to increase the rate of disarticulation (22). Based on daily data reports from Environment Canada, the temperature readings showed a steady rate of increase throughout March and April (17).

Weathering stages proposed by Behrensmeyer (1978) describe stage 0 as the absence of cracking and flaking, and the presence of soft tissue and greasy bone, which is likely to occur between 0 and 1 year (18). In this study, both cracking and flaking were observed on Day 126, as early as 4 months subsequent to exposure. Skeletonization of four fleshed specimens occurred in less than 6 months. Based on Behrensmeyer's model, evidence of flaking is not visible until 2–6 years (18). The results of this study demonstrate the importance of examining differential rates of weathering based on microenvironmental context, particularly with respect to estimating time since death.

Longitudinal studies are vital to understand the effects of taphonomic stress on the skeleton. Careful observation and chronological organization of data through photography are essential to successfully recognize and interpret taphonomic change. Each taphonomic process outlined by this study has the potential to disguise antemortem injury. One must carefully examine large, circular openings in the skull that may represent the remnant evidence of BFT. The circular nature of the damage indicates that trauma occurred perimortem, rather than postmortem, as postmortem damage tends to produce right-angled, rectangular

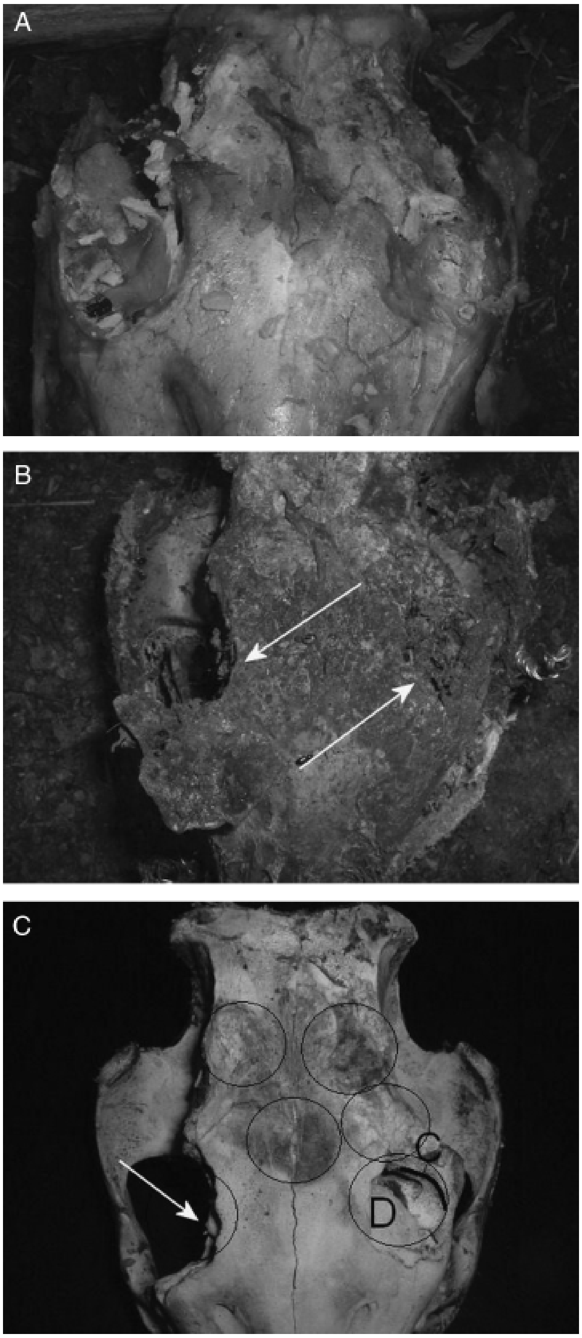

FIG. 6—*Soil erosion/protection. PIN 9 on Day 6, 300, and 362 shown here in 6A–C, respectively, progressively show the effects of soil erosion and protection. The impact site on the left frontal bone has been preserved by the presence of soil, whereas the impact site on the right frontal bone has been displaced by the weight and erosion of soil, replacing injury margins with scalloped edges. Evidence of hematoma staining is also present.*

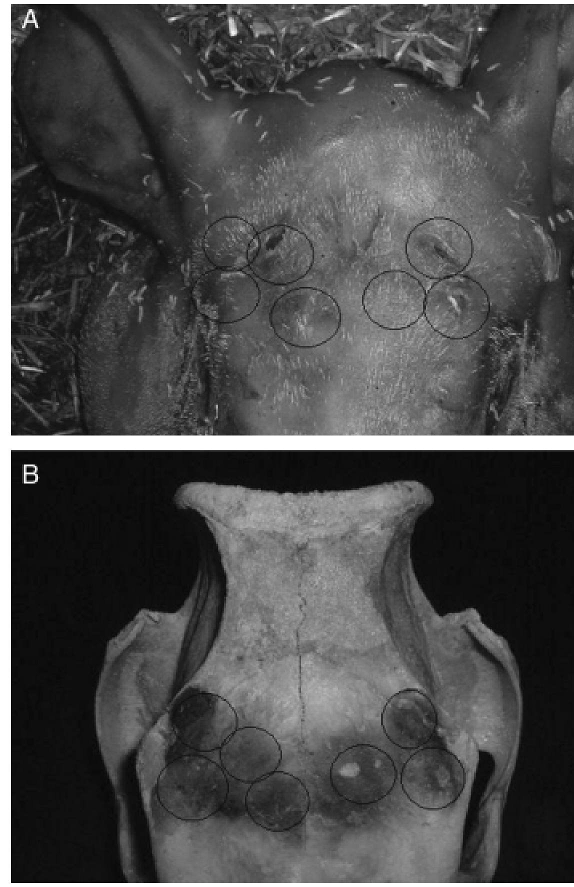

FIG. 7—*Bruising. PIN 5 on Day 9 and 362 are shown here in 7A and B, respectively. Although the investigator failed to penetrate the outer table of bone in this specimen, bruising of the bone is still present after one year of exposure to environmental stress.*

fractures. The edges of the bone will show no evidence of healing, as observed in antemortem trauma, nor will fractures necessarily originate at the suture as observed in postmortem trauma. Instead, (1) the affected bone(s) will lie depressed below the plane of adjacent bones with evidence of concentric rings and linear fractures, which are unlikely to cross sutures or other existing radiating fractures, (2) discoloration at the edges of fracture will not be present, and (3) hematoma staining often occurs around the impact site and neighboring fractures. Investigators must also check for changes in the direction of linear fractures to distinguish postmortem damage from perimortem trauma (Fig. 3*B*).

A single blow to the skull by a blunt instrument may not perforate the bone. It may instead, result in increased inbending but no new fracturing. Multiple blows to the skull may be necessary in order to penetrate the outer table of bone. Thus, the number of identifiable impact points represents the minimum number of blows. With repeated impact, the edges of fractured bone tend to rub together to create knapping and flaking of cortical bone.

The effects of the seven taphonomic variables examined in this study decrease the chance of identifying the number of lesions, direction/force of blows, patterning/timing, and location of lesions (Table 5). Typical indicators of BFT such as radiating, concentric, or hinge fracture may be disguised by the effects of environmental stress. We recommend cautious examination of areas that are affected by taphonomy in order to detect underlying evidence of BFT. Thus, the involvement of an experienced forensic anthropologist in processing an outdoor scene is crucial to correct interpretation of the remains. The standards for recording and identifying the presence of BFT suggested by this research are intended to provide investigators with preliminary guidelines for examining BFT on remains affected by taphonomic processes.

Controlling variables in taphonomic research is difficult as factors of environmental stress on skeletal material produce variable and interdependent results. As these analyses are part of a pilot study, there is without doubt opportunity to expand the scope of this research. We encourage forensic anthropologists to publish

TABLE 5—*Morphological aspects of BFT due to taphonomic changes.*

Taphonomic Changes	Appearance of Injuries	Injury Margins	Characteristics
Freeze–thaw cycle	Concentric, radiating and/or hinge fracture(s) initiating from the point of impact are indiscernible	Irregular serrated edges; flaking of periosteum; protruding wedges of bone(s)	Dehydrated, brittle bone; cracking parallel to bone fiber structure; deep splitting of the outer table of bone; roughened texture; radiating fracture(s) originate from suture lines
Presence/weight of Rain/snow	Radiating and/or hinge fracture(s) initiating from the point of impact are indiscernible	Border of outermost concentric fracture intact; irregular and/or angular edges; flaking of periosteum	Dehydrated, brittle bone; cracking parallel to bone fiber structure; flaking/splitting of adjacent outer table of bone; roughened texture; radiating fracture(s) originate from suture lines
Movement by animals	Inward depression and/or complete displacement of bone at the impact site(s); evidence of concentric and/or radiating fracture still present	Irregular, sharp, angular edges; affected bone lies depressed beneath the plane of adjacent bone(s); border of outermost concentric fracture intact	Edges of bone along sutures are damaged; fragile bones of the skull are damaged
Bleaching/grass/soil staining	Impact site(s) are highlighted from contrast in color of bone; concentric, radiating and/or hinge fracture(s) present	Discoloration from staining is consistent along injury margins	Dehydrated, brittle bone; prolonged exposure to sunlight may result in cracking parallel to bone fiber structure and/or flaking/splitting of adjacent outer table of bone
Soil erosion	Radiating and/or hinge fracture(s) initiating from the point of impact is indiscernible	Irregular edges; finely scalloped; serrated; border of outermost concentric fracture intact	Loss of cortical bone; infilling of exposed orifices; fragile bones of the skull are damaged
Carnivore scavenging	Concentric, radiating and/or hinge fracture(s) initiating from the point of impact are intact	Sharp irregular/angular edges	V-shaped punctures; pits; scoring; furrows; claw marks; fragile bones of the skull are damaged

BFT, blunt force trauma.

case examples to increase the database for comparative studies, to contrast microenvironmental patterns, and to detail unique taphonomic changes not discussed herein.

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