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Identification of a Pre-Contact Polar Bear Victim at Native Point, Southampton Island, Nunavut, Using 3D Technology and a Virtual Zooarchaeology Collection

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ABSTRACT. The skeletal remains of an adult Sadlermiut woman with obvious trauma to her cranial and post-cranial skeleton were excavated from Native Point (KkHh-1), Southampton Island, Nunavut, in 1954. In order to determine the possible cause of this damage, we first documented the skeletal injuries using traditional bioarchaeological techniques. We then created a three-dimensional model of the cranium and mandible to permit better visualization and analysis of the cranial lesions, some of which were obscured by post-depositional weathering. This model was imported into a virtual environment in order to compare the lesions with the craniodental structure of four Arctic carnivore species available as digital models through the Virtual Zooarchaeology of the Arctic Project (VZAP), an online comparative faunal collection. We eliminated all but the polar bear (*Ursus maritimus*) using this process, which suggested that an individual of this species was responsible for the skeletal trauma. We further identified a minimum number of "bites" on the cranium, some with overlapping lesions, which suggested a possible attack sequence. Use of a virtual environment and an online comparative collection were critical to this process and represent a new technique for evaluating past skeletal trauma and its causes.

Key words: Sadlermiut, skeletal trauma, polar bear (*Ursus maritimus*), Virtual Zooarchaeology of the Arctic Project (VZAP), digital technology, virtual technology

RÉSUMÉ. En 1954, lors de travaux archéologiques sur le site Native Point (KkHh-1), île Southampton, Nunavut, les restes du squelette d'une femme adulte de la culture Sadlermiut portant des signes évidents de traumatismes crânien et post-crânien avaient été excavés. Dans le but de déterminer les causes possibles de ces dommages, nous avons d'abord documenté les lésions squelettiques à l'aide de techniques bio-archéologiques traditionnelles. Ensuite, nous avons créé un modèle en trois dimensions du crâne et de la mandibule pour permettre de bien visualiser et analyser les lésions crâniennes, notamment parce que certaines d'entre elles étaient obscurcies par l'érosion post-dépositionnelle. Ce modèle a été importé dans un environnement virtuel afin de comparer les lésions à la structure cranio-dentaire de quatre espèces carnivores provenant de l'Arctique dont les modèles figurent déjà dans la collection ostéologique comparative en ligne du projet VZAP (Virtual Zooarchaeology of the Arctic Project). Nous avons ainsi éliminé tous les carnivores à l'exception de l'ours polaire (*Ursus maritimus*), laissant penser qu'un membre de cette espèce serait responsable des traumatismes du squelette de cette femme. Nous avons également identifié des morsures sur le crâne de cette femme, suggérant une possible séquence d'attaques, ne serait-ce que par la présence d'une série de lésions qui se chevauchent. L'utilisation d'un environnement virtuel et d'une collection comparative virtuelle a joué un rôle déterminant dans ce processus et représente une nouvelle technique pour évaluer les traumatismes squelettiques anciens et leurs causes.

Mots clés : Sadlermiut, traumatismes squelettiques, ours polaire (*Ursus maritimus*), Virtual Zooarchaeology of the Arctic Project (VZAP), technologie numérique, technologie virtuelle

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INTRODUCTION

In 1954, the partially exposed skeleton of an adult Sadlermiut Inuit woman (XIV-C:752) was excavated from a tent ring at the Native Point site (KkHh-1, Fig. 1) on Southampton Island, Nunavut, by Henry B. Collins (Collins, 1954, 1954–55a, b). Collins (1954–55b) identified the remains as "Burial 24" and noted several points of presumed post-mortem injury on the cranial and post-cranial skeleton, including three large "dents" on the cranium and

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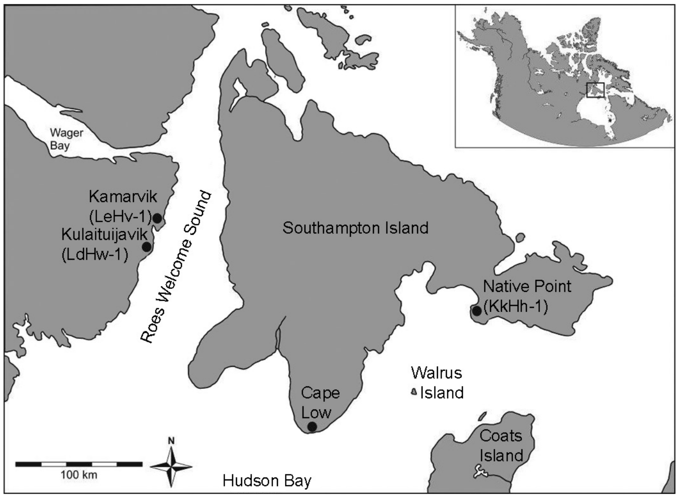

FIG. 1. Southampton Island, showing locations mentioned in the text.

holes through both parietals that he suggested were caused by a firearm. These traumas appear not to have been examined further until our work, which suggests a very different cause for the damage.

In the following analysis, we first provide a brief overview of the Sadlermiut and Burial 24 before describing several areas of injury on the physical remains, currently housed at the Canadian Museum of History (CMH). We then outline how a fully rendered three-dimensional (3D) digital model of the cranium was created so that we could better visualize and quantify the numerous points of damage on it. This process represents a new method for identifying carnivore-induced trauma on skeletal remains. We used a virtual environment to properly scale and compare the 3D model of the woman's cranium to digital models of several Arctic carnivores available via the website of the Virtual Zooarchaeology of the Arctic Project (VZAP), an online comparative faunal collection (Betts et al., 2011; VZAP, 2014). Finally, we report the results of our work and our conclusion that the traumas identified on the Sadlermiut cranium are consistent with the dental structure of a polar bear (*Ursus maritimus*), indicating that an individual of this species was most probably responsible for the woman's injuries.

THE SADLERMIUT AND BURIAL 24

The Sadlermiut were a remarkably isolated Inuit group who had minimal contact with other contemporary Inuit and European populations throughout most of the 19th and early 20th centuries. Comparatively little ethnohistoric information on their society exists, and this fact, along with apparently unique aspects of their culture, has often caused them to be described as "mysterious" or unusual (e.g., Collins, 1956; Taylor, 1959). What is known for certain is that almost all of the Sadlermiut living at Native Point, their last village, were dead by the spring of 1903, victims of an epidemic introduced into the commercial whaling camps of Hudson Strait and Hudson Bay by a European supply ship the previous summer and fall (Ross, 1977).

The illness, probably a gastric or enteric infection, appears to have been virulent and highly contagious, and it was still active in the autumn of 1902, when a group of normally reclusive Sadlermiut visited Southampton Island's only whaling station at Cape Low. The Sadlermiut rapidly became so sick that they were unable to travel unaided; the disease was brought to Native Point when Aivilingmiut Inuit working at Cape Low were enlisted to bring the sick Sadlermiut home. The entire community was evidently infected, as all but three Sadlermiut were dead when outsiders returned to Native Point in the spring. Aside from some early victims who may have been buried, many lay in and around the dwellings where they had died (Mathiassen, 1927; Taylor, 1960; Marsh, 1976).

Mainland Inuit briefly reoccupied Native Point during the 1920s, although they had abandoned the site by the time researchers arrived in the mid-1950s (Bird, 1953). Henry B. Collins (1954–55b, 1955, 1957, 1958) investigated several dwellings and excavated 34 graves in 1954 and 1955; of those burials, eight were located within the village boundaries and two were situated inside habitation features. Collins (1954, 1954–55a, b) noted that Burial 24 consisted of the incompletely exposed skeleton of an adult woman located inside an old stone tent ring on the southeastern outskirts of the village (Fig. 2). The woman had been placed in a flexed position, apparently on her left side, as her left hand was located underneath her lumbar vertebrae; her skeletal remains are largely complete although her cranium and mandible, as well as parts of the pelvis and femora, were above ground and weathered. The remains are free of pathology with the exception of the femurs, right tibia, left radius, and cranium, which all display signs of trauma. It is unclear whether any special grave feature was constructed inside the tent ring and no drawings or photographs of Burial 24 can be located; a calibrated 2δ radiocarbon range of AD 1656–1890 (uncalibrated 682 ± 42 BP) was obtained directly from the remains (Coltrain et al., 2004).

OVERVIEW OF TRAUMA TO THE POST-CRANIAL SKELETON

Examination of the woman's post-cranial skeleton revealed the presence of traumatic lesions on four elements of the lower body. The most obvious are comminuted fractures of both femoral shafts, where the left has broken into three sections and the right into at least four (a portion of the latter was not recovered). This type of injury typically involves a high-energy direct force mechanism, which in this case, judging by the pattern of multiple radiating linear fractures, originated behind the woman (e.g., Miller and Miller, 1972; Kress et al., 1995). The fractures are sharp and have inwardly beveled and obliquely angled edges that are the same colour as the undamaged bone, indicating perimortem timing (Merbs, 1989; Buikstra and Ubelaker,

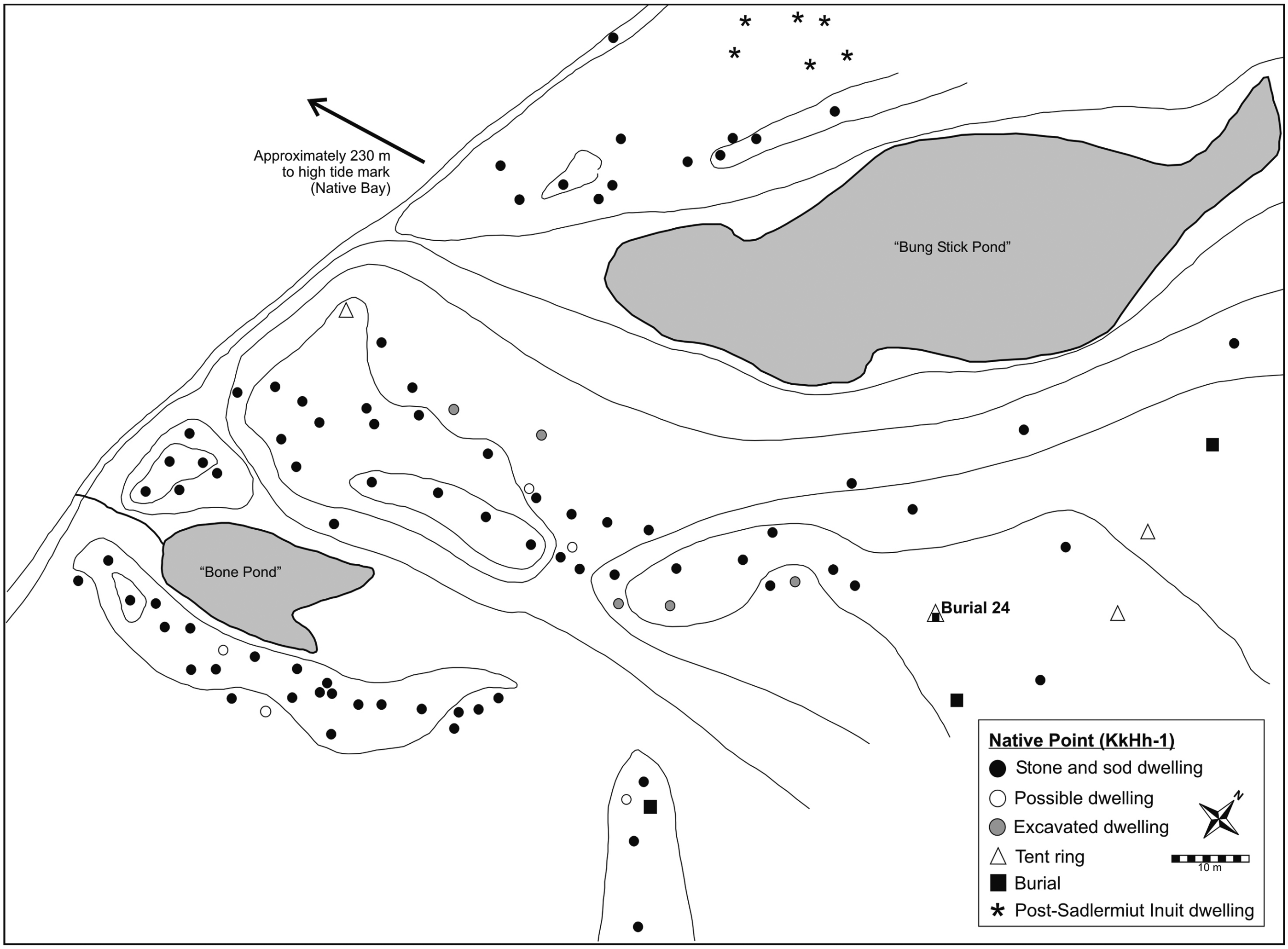

FIG. 2. Map of the Native Point village site (KkHh-1), adapted from Taylor and Emerson (1954), indicating the location of Burial 24.

1994; Kress et al., 1995; Ubelaker and Adams, 1995; Lovell, 1997; Sauer, 1998; Wieberg and Westcott, 2008). There is no visible evidence of osteogenic response, suggesting no healing prior to death.

A penetrating crush fracture was also located on the metaphyseal region of the right tibia, distal to the lateral condyle and beside the superior fibular articular surface (the fibula itself is undamaged). The lesion is defined by sharp oblique boundaries and uniform colouration, which, in combination with inwardly oriented bone fragments, suggests the application of substantial direct force while the bone was fresh. As with the femora, there are no visible indications of healing before death. Finally, a distinct round puncture is clearly visible on the anterior face of the radial tuberosity of the left radius, immediately below the neck. A narrow section of bone extending from the perforation to the lateral surface of the radial head is also missing, although weathering of the proximal radius has made it impossible to establish when this occurred.

TRAUMAS VISUALLY IDENTIFIED ON THE CRANIUM

The cranium had clearly lain exposed on the ground surface for some time and was significantly weathered on the right frontal, temporal, parietal, and occipital bones (Fig. 3). These areas are sun-bleached, have some lichen encrustation, and display exfoliation of the outer table consistent with Stage 3 weathering (Buikstra and Ubelaker, 1994: Table 5, Fig. 68); this erosion sometimes hampered analysis. In contrast, the left half of the cranium is better preserved and is only lightly bleached, with little or no exfoliation or cracking. This implies that the woman had lain with her left side against the ground (Behrensmeyer, 1978), consistent with Collins' (1954–55b) report that the left hand was positioned underneath the vertebrae.

Fourteen loci of cranial trauma were visually identified and are described below; discussed in a subsequent section are two additional lesions (xv and xvi), effectively invisible to the naked eye, that were located during our digital analysis. These injuries, which include concentric, comminuted, crush, and penetrating fractures, were instrumental in our

FIG. 3. Cranium and mandible of XIV-C:752. Left, anterior, and right views show visible lesions and differential surface weathering.

FIG. 4. Anterior view of the cranium indicating the position of lesions i–v.

identification of a large-bodied carnivore as the mechanism of injury.

Five traumatic lesions (i-v) were identified on the frontal bone (Fig. 4). Lesion i, a compression fracture defined by a 13.61 × 6.89 mm area of crushing on the ectocranial surface, is comparatively small considering the depth of bone penetration (almost 3 mm) and has two associated fractures radiating from it (a catastrophic fracture extending through lesion i relates to lesion x, discussed separately). Multiple bone fragments remain in situ, indicating that the bone was damaged while soft tissue remained (Ortner and Putschar, 1985:72).

Lesion ii is a concentric depressed fracture measuring 24.25 mm by 21.39 mm immediately right of the midline. Lesion iii is similarly sized but more pronounced, as the ectocranial surface was pushed through the inner table, displacing the endocranial surface. Small inwardly angled

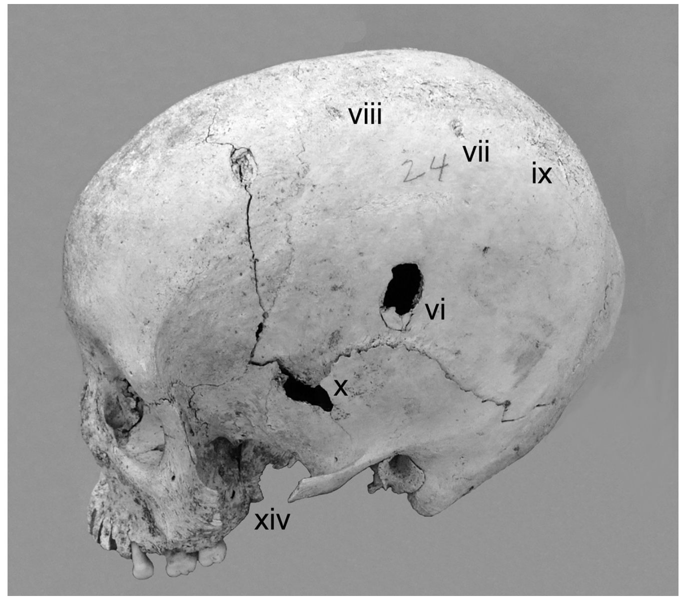

FIG. 5. View of the left side of the cranium indicating the position of lesions vi–x, as well as possible lesion xiv.

adhering bone fragments define this lesion, signifying perimortem timing, and one of two linear fractures extending from it intersects with lesion xi in the right parietal. Lesion iv is slightly larger than lesion iii but is limited to the bone's outer table; no radiating fractures could be identified, possibly because of surface weathering. Lesion v consists of a shallow 20.47 × 5.01 mm linear depression on the left frontal bone. Although there was no visible fracturing, local deformation implies that micro-fracturing consistent with slow-load application of compressive force to pliable bone occurred (Berryman and Haun, 1996; Berryman and Symes, 1998; Wheatley, 2008; Passalacqua and Fenton, 2012).

Four points of trauma were identified on the left parietal bone (Fig. 5). Lesion vi, a complete 10.23 × 14.91 mm puncture located above the external auditory meatus, retains in situ bone fragments, which suggests perimortem timing. Lesions vii and viii, located midway between the sagittal and squamosal sutures, are sharply defined contact points, which compromised the ectocranial table. Lesion vii consists of a 6.45 × 3.60 mm crushed area from which extend two shallow v-shaped grooves whose proximity to one another suggests related instances of direct contact; the grooves are quite smooth, indicative of fresh bone. Lesion viii consists of two linear gouges similar to lesion vii but without an obvious area of crushing. Lesion ix appears comparatively minor, implying less force, and is defined by concentric fracture lines enclosing an 11.83 × 11.22 mm area.

Lesion x consists of a complete 15.44 × 17.06 mm puncture and two associated fractures on the anterior portion of the left temporal bone (Fig. 5). While one fracture is relatively minor, the other radiated along the squamosal, sphenoparietal, and coronal sutures before traveling through lesion i and dissipating at lesion ii. Measuring more than

FIG. 6. View of the right side of the cranium indicating the position of lesions xi–xiii.

90 mm in length, it compressed the anterior parietal and left inferior frontal bones into the cranial vault.

Three lesions were identified on the more weathered right parietal (Fig. 6). Lesion xi is composed of a 17.95 × 13.36 mm puncture and three linear fractures, one of which extends to lesions ii and iii on the frontal bone. As with lesion x, the force powering lesion xi was sufficient to displace the anterior right parietal bone endocranially. Two additional lesions, xii and xiii, are near the middle of the parietal. Lesion xii is the more inferior and consists of a shallow depression; inside the lesion are two u-shaped fractures, the larger and lower partly overlying the other, indicating it is more recent. Lesion xiii also presents as a depression defined by fracture lines, except that near its centre is a single point of crushing, representing the point of direct contact. The characteristics and placement of the two lesions suggest a mechanism of injury that chattered along the bone's surface while it was fresh.

The final area of visible cranial damage involves the left zygomatic process, where a 21 mm section of the posterior zygomatic and anterior temporal bone is missing (Fig. 5). However, because this area is prone to post-burial breakage, and considering that we could not determine when the damage occurred, it is considered a possible trauma (lesion xiv).

IDENTIFYING THE SOURCE OF THE CRANIAL TRAUMA

When we considered the range and extent of damage to the woman's cranial and post-cranial skeleton, particularly the evidence for massive force and the occurrence of what seemed to be paired cranial lesions, it became clear that the traumas were not attributable to a human agent (e.g., Walker, 2001) and in particular were not consistent with a peri- or post-mortem gunshot wound, as originally suggested by Collins (1954–55b). The evidence instead pointed to a large-bodied and presumably carnivorous animal.

Merbs (1989, 1997) had previously identified a number of possible polar bear victims at two Thule Inuit sites (prehistoric or early contact, or both) on the west coast of Hudson Bay, opposite Southampton Island (Fig. 1). An unspecified number of individuals from undisturbed graves at the Kulaituijavik site (LdHw-1) were highly fragmented and incomplete, although otherwise very well preserved, with bones showing "deep indentations as from large canines, [which] indicate that these individuals had been the victims of polar bears" (Merbs 1989:183). The condition of two additional individuals from the nearby Kamarvik site (LeHv-1) again led Merbs to identify polar bear casualties; in addition to their fragmented state, these remains exhibited sharp breakage planes and had been cleanly broken at points where thick and dense cortical bone was present, a combination symptomatic of "parts of the body having been ripped away" (Merbs, 1997:261). At least some smaller bone fragments may have been digested.

In marked contrast with those sites, the human remains recovered from Burial 24 are virtually complete and lack the extreme fragmentation reported by Merbs. Despite this obvious difference, however, we nonetheless suspected that a bear might also have been responsible for the Sadlermiut woman's skeletal damage, particularly the cranial puncture wounds, which we believed were caused by canines. In order to test our theory, we identified four large-bodied carnivores who are either resident or occasional visitors to this part of Nunavut for comparative purposes: the northern tundra wolf (*Canis lupus hudsonicus*), black bear (*Ursus americanus*), grizzly bear (*Ursus arctos horribilis*), and polar bear. As all are theoretically capable of inflicting at least some of the trauma, we hoped that a direct comparison between the cranial lesions and the unique craniodental structure of each species would allow us to identify the animal involved.

Although detailed descriptions of bite mark injuries involving humans and wild animals are largely lacking (e.g., Freer, 2004), odontological studies with similar goals have been successfully undertaken in modern cases when investigators need to identify the species, or even the individual animal, involved in human-animal and animal-animal encounters (e.g., Glass et al., 1975; George et al., 1994; Rollins and Spencer, 1995; Nambiar et al., 1996; Murmann et al., 2006; De Giorgio et al., 2007; Lowry et al., 2009; Shields et al., 2009; Bergman et al., 2010); a smaller number of taphonomic studies have also been described (e.g., Sutcliffe, 1970; Brain, 1981; Boaz et al., 2000; Domínguez-Rodrigo and Piqueras, 2003; Delaney-Rivera et al., 2009; Gignac et al., 2010). In some of these cases, a direct comparison was made between wound marks and an individual animal, while in other instances, where species identification was the goal, the spacing between paired canine marks (intercanine width or canine spread) was considered against known ranges for candidate species (e.g., Elbroch, 2006:83 – 88) in order to narrow the list of possible perpetrators.

Unfortunately, this technique is less useful for closely related species, juveniles, and species for which there is marked sexual dimorphism because of the large and frequently overlapping size ranges that are produced. An additional variable of critical significance for this study relates to the manner in which intercanine width ranges are obtained. As discussed by Murmann et al. (2006), the conical shape of the canines means that intercanine widths will vary on the same individual depending upon where measures are taken, with the greatest distance occurring between the cusps and the smallest where the teeth erupt from their sockets. This means that the intercanine width measure obtained for a superficial bite mark involving minimal canine engagement will be larger than the width measure obtained for a deeper puncture wound made by the same animal because these deeper bites involve progressively more of the teeth (e.g., Murmann et al., 2006: Figs. 5 and 6; also Bernitz et al., 2012: Figs. 4 and 5).

To resolve this ambiguity, Murmann et al. (2006) advocate producing two intercanine widths in order to establish ranges appropriate for deep bites (mesial bone height, or MBH, measured using the alveolar bone of the socket), as well as for less forceful bites involving little or no tooth penetration (canine cusp tip to canine cusp tip, or Tip). Unfortunately, while Murmann et al. (2006: Tables 14 and 15) do provide MBH and Tip width ranges for gray wolves and grizzly and black bears, polar bears were not included. Intercanine widths were also not incorporated into dentition studies dealing more specifically with ursids (e.g., Sacco and Van Valkenburgh, 2004; Christiansen, 2007, 2008; Christiansen and Wroe, 2007).

This omission presented a serious problem for our analysis. If we were to compare the Sadlermiut woman's cranial injuries, particularly those suspected to be paired upper or lower canine marks, against known ranges in order to confirm or eliminate species from suspicion, how could we proceed? We had immediate access to only one complete skull and mandible at the CMH, that of an approximately 140 kg black bear with a maxillary intercanine width of 33.61 mm (MBH) or 46.91 mm (Tip) and mandibular width of 12.12 mm (MBH) and 41.83 mm (Tip). Direct comparison of that bear's dentition with the suspected paired upper or lower canine marks demonstrated that an animal of this size was far too small to be responsible for the damage to the woman's cranium. Although this result would seem de facto to eliminate the smaller northern tundra wolf, we could not exclude a larger black bear. We remained hopeful that we could more conclusively compare the traumatic lesions against the craniodental morphologies of our shortlist of predator species, at the same time checking the accuracy of our proposed injury pairings.

One option was to bring the human cranium to a collection of carnivore skulls with multiple differently sized individuals per taxon and compare the bite marks manually. However, this process proved cumbersome because it involved articulating the mandible and cranium of both the human specimen and the animal comparative, and then manoeuvring each to assess bite fit, pattern, and sequence. Further, the degree of handling involved (requiring at least two people) and the amount of contact between specimens was not appropriate for the fragile human cranium or the brittle teeth of the comparative collection. Moreover, the number of lesions identified on the human cranium and the complexity of the inferred bite sequence were such that it was difficult to code each trauma in relation to each bite.

Our solution, described below, was to virtually recreate the relevant skeletal elements in a high-resolution 3D environment where the required manipulations could be conducted without endangering the actual skeletons, with the entire process systematically recorded to track the reconstructed trauma sequence. To begin, we created a high-resolution 3D digital model of the human cranium and mandible at the CMH using a laser scanner. To provide the comparative animal crania, we accessed a repository of high-resolution 3D digital models available on the VZAP website. VZAP offers online a virtual comparative collection of cranial and post-cranial elements for 169 northern vertebrate species (Betts et al., 2011), which includes multiple specimens of each of the four species we wished to test. Once the virtual human and animal crania were selected, they were imported into 3D rendering software at the Idaho Virtualization Laboratory to determine the probable species involved and the potential trauma sequence.

MODELING THE HUMAN CRANIUM

As noted previously, surface weathering complicated analysis of some points of trauma on the Sadlermiut woman's cranium. In order to fully capture details of the injuries and facilitate comparison with the VZAP skulls, we generated a high-resolution 3D digital model of the cranium that would facilitate isolation of individual bite marks among the 14 visible points of damage. We then compared the virtual human and animal models to determine whether the dentition of any of the four suspected species matched the cranial trauma.

Virtual models are highly advantageous because they are fully interactive and allow researchers to view, rotate, and re-scale scanned objects in three dimensions and in real time to better view select anatomical landmarks (Strait and Smith, 2006; Niven et al., 2009; Betts et al., 2011; Kuzminsky and Gardiner, 2012). While not without disadvantages, including file size and concerns regarding accuracy, these models can record, highlight, and preserve details that might be overlooked or otherwise remain invisible using more conventional analyses. Use of virtual objects offers a further benefit in that it allows collections to be shared among researchers working in different locations, permitting full collaboration on materials that cannot or should not travel from their repository.

To create a high-resolution virtual model of the human cranium and mandible, we followed a four-step process: scanning, trimming, aligning, and fusing. We used a portable multi-laser NextEngine surface scanner and ScanStudio HD 1.1.1 visualization software capable of producing models accurate to circa 50 microns. While protocols can vary with specific research requirements (e.g., Weber and Bookstein, 2011), in this case details of the cranium's surface were recorded by first initiating a series of high-resolution 2D colour photographs, taken by the scanner, which provided the finished model its texture and realism. A total of 12 anterior-posterior and 12 superior-inferior scans were then made, recording surface features as individual data points. These points form a polygon web or mesh structure that gives the model its 3D shape and structure. Each scan was manually trimmed to remove unnecessary elements, as well as to reduce the point count below 1 500 000, as ScanStudio HD 1.1.1 cannot process scans with a greater density. Scans were then aligned and fused into a single 3D model viewable with a texture map (2D photographs are wrapped onto the model, creating a colour-realistic surface), as a solid model (without colour data), or as a web structure displaying the individual data points.

The virtual cranium can be freely manipulated, rotating in 360˚ to help us visualize the injuries and evaluate and measure specific loci of interest. Significantly, the variety of digital modes in which we could view the cranium allowed us to see traumas in weathered areas that were essentially invisible to the naked eye (see next section).

IDENTIFYING INDIVIDUAL BITE MARKS

Creating a digital model of the Sadlermiut woman's cranium offered a number of immediate advantages. Through the scanning and rendering process, we could minimize some of the "noise" caused by weathering and lichen encrustation on the actual cranium, and in the process, sharpen certain details, which allowed us to identify traumas that were otherwise practically invisible because of surface deterioration. These included two linear lesions (lesions xv and xvi) on the occipital, directly posterior to and flanking the foramen magnum (Fig. 7). Like perimortem lesion v, lesions xv and xvi are shallow areas of deformation likely caused by micro-fracturing and crushing of the outer cortical bone, injuries consistent with a force that was applied and dragged across the cranium's surface. Unfortunately, we were unable to identify the direction of this force as the trauma is difficult to see; the distortion can be fully examined only by using oblique lighting in a virtual environment.

Our digital environment was created within Z-Brush, a popular 3D rendering software package. Z-Brush allowed us to virtually articulate the human mandible and cranium, as well as create a virtual "armature" that allowed us to anchor the mandible's condyles precisely on the mandibular fossae and rotate the mandible and cranium in anatomical

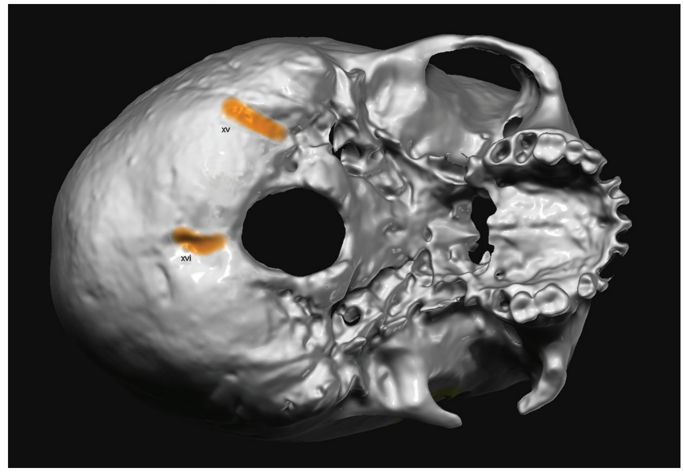

FIG. 7. Digitized cranium (from below) indicating the position of lesions xv and xvi, which are invisible to the naked eye.

position. Using the software's shading and lighting options, we attempted to determine possible matched pairs of "bites" that accounted for the traumas on the cranium. In practice it was often easy to determine paired lesions made by upper or lower canines, but more difficult to establish which pair related to which other pair when attempting to identify a single bite event. To aid this process, we colour-coded lesions believed to be related using the software's paint option, something which proved extremely useful when we next imported digital animal crania to test our identified bites. As a procedural note, we attempted to do this with the actual cranium (using acid-free dot stickers, since our collection protocols do not permit directly marking the surface of human remains). However, we found the process impractical: the stickers did not adhere well to the cranium's weathered surface and were easily dislodged during handling.

IDENTIFYING A LIKELY PREDATOR

In order to assess whether any of our candidate carnivore species could have inflicted all 16 identified traumas, we systematically imported virtual models of the woman's cranium and mandible and each carnivore skull and mandible into an interactive digital environment. Each mandible was precisely articulated to its skull using an armature that allowed us to virtually open and close the selected specimen's mouth. For each initial assessment, we maintained the original scale relationships of the individual carnivores, meaning that comparisons were carried out to scale for each specimen. We began by placing the carnivore's canines over what we considered to be a pair of traumas, lesions i and iv on the frontal bone (Fig. 8a–d). We worked systematically from there, virtually placing the upper canines or lower canines of the selected species at the locations of these two lesions in order to assess their "fit." This process was painstaking and time-consuming, as indicated below.

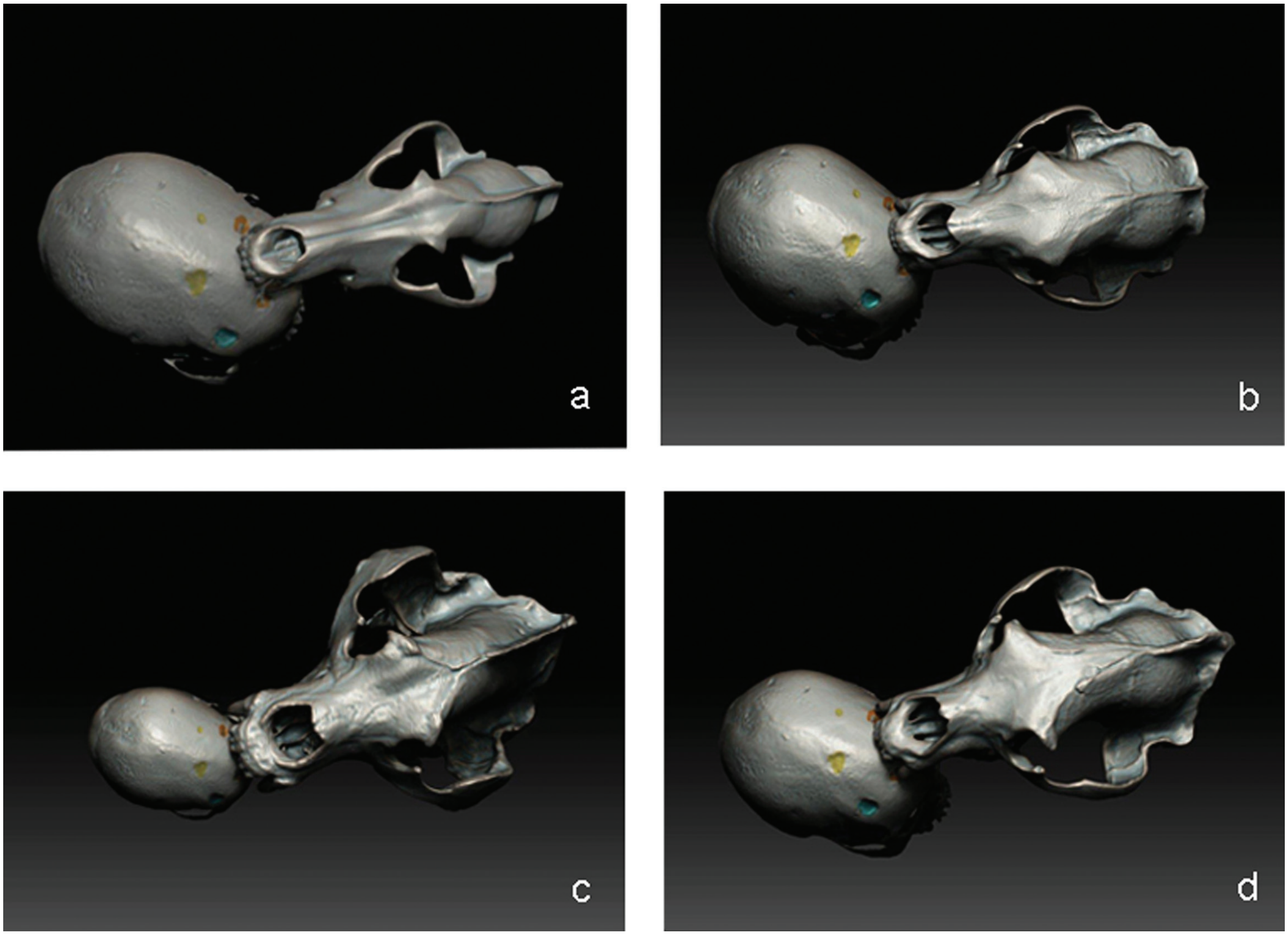

FIG. 8. Assessing fit between paired lesions i and iv (Bite A) and the upper canines of selected carnivore species: (a) gray wolf, (b) black bear, (c) large old grizzly bear, (d) grizzly bear.

Canis lupus hudsonicus (Northern Tundra Wolf)

The northern tundra wolf is a subspecies of the circumpolar gray wolf (*C. lupus*) and has an extensive range that includes the interior and coast of Hudson Bay and its islands (Nowak, 1983), although wolves were extirpated from Southampton Island in the late 1930s (Manning, 1942). Sexual dimorphism is present: males are both larger (about 90 cm at the shoulder) and heavier (up to 79 kg) than females (Banfield, 1974; Paquet and Carbyn, 2003). The tundra wolf subspecies also has a geographic size cline: wolves in the Kivalliq (Keewatin) region are among the largest (Mulders, 1997).

Information on intercanine width has been generated by Mulders (1997: Tables 8 and 9) using the Tip technique (approximating a superficial bite). He reports an overall upper intercanine range for *C.l. hudsonicus* of 46.8–51.7 mm for males and 44.2–48.0 mm for females. The somewhat larger Kivalliq wolves, the extant group closest to Southampton Island, have a mean upper width of 48.37 mm (male) and 45.17 mm (female). In comparison, the ranges for *C. lupus* are 40.45–54.46 mm for males and 35.87–50.01 mm for females (Elbroch, 2006:84). Murmann et al. (2006: Table 16) combine MBH and Tip to produce an upper intercanine range of 2.3–5.1 cm.

Because VZAP does not have a northern tundra wolf in its collection, we used an adult male gray wolf (*Canis lupus*). The tip-to-tip upper intercanine width for that specimen was 41.03 mm, within the range expected for *C. lupus* but smaller than that for *C. l. hudsonicus*. However, as the VZAP skull and mandible are fully scalable, we were able to enlarge them virtually so that the intercanine width was equivalent to that of *C. l. hudsonicus*. Using Z-Brush software, we then manipulated the digital mouth in order to conduct an association analysis between the wolf's dentition and the lesions situated on the frontal bone of the human cranium (Fig. 8a).

It was immediately clear that the scaled wolf was unable to open its mouth sufficiently to inflict any of the bites on the woman's cranium. Even if it were possible, the wolf's comparatively elongated but narrow rostrum and upper/lower intercanine widths are too small to accommodate the most superficial of the paired canine marks we identified, or any other combination of traumas. The wolf's canines were also too small to account for the size of the punctures, even allowing for some wound distortion. We thus confidently eliminated the northern tundra wolf from our list of potential perpetrators.

Ursus americanus (American Black Bear)

American black bears are the smallest of the three North American ursids; males typically weigh 115 – 270 kg and females 92 – 140 kg (Banfield, 1974), although some males can weigh more than 300 kg (Pelton, 2003). Black bears also have the largest geographic range of the North American species, with a northern limit surpassing 60˚ N on both coasts of Hudson Bay, although they have never been reported on the islands of the Arctic Archipelago. Dietary omnivores and opportunists, black bears are less predacious than grizzly and polar bears (Tate and Pelton, 1983), although their proximity to inhabited areas means they more frequently contact humans (Herrero and Fleck, 1990). Most aggressive interactions with humans involve habituated black bears (Herrero, 1985), and predacious events involving injury or death to a person are known (Herrero and Fleck, 1990; Herrero and Higgins, 1995; contra Pelton, 2003).

Like many ursids, black bears have unspecialized dentition (Larivière, 2001; Christiansen, 2007), with an intercanine width range (Tip method) for males of 44.04 – 60.37 mm and 45.95 – 55.24 mm for females (Elbroch, 2006:85). As described previously, our initial hands-on assessment of the cranial traumas using an adult black bear skull and mandible reaffirmed our belief that the lesions represented canine marks, but they also showed that the traumas were caused by an animal larger than our specimen. Following the procedures outlined above for the VZAP wolf, we placed the VZAP black bear and human cranium in a digital environment to compare dentition against lesions. The black bear's intercanine width remained too small to match the lesions (Fig. 8b), even when it was scaled beyond the published intercanine limits for this species. This result confirmed that of our original direct test, which indicated that *U. americanus* could not be responsible for the woman's cranial injuries.

Ursus arctos horribilis (Grizzly Bear)

Observations of grizzly bears in the western Canadian Arctic Archipelago suggest that their range can be fluid (e.g., Doupé et al., 2007) and is potentially associated with changing climatic conditions (e.g., Rockwell et al., 2008). Banfield (1974) places the eastern range of grizzly bears at Baker Lake, although their distribution originally extended to the Hudson Bay coast and as far east as Labrador (Elton, 1954; Harington et al., 1962; Spiess, 1976; Spiess and Cox, 1976; Schwartz et al., 2003; Loring and Spiess, 2007). Harington et al. (1962) report extralimital sightings on Southampton Island, establishing that transient individuals at least occasionally venture here, and for this reason we included *U. arctos horribilis* among our species to be evaluated.

Grizzly bears possess a heavy and distinctive skull and dentition that reflect a strong degree of sexual dimorphism (Schwartz et al., 2003). Body size is also highly variable, and individuals of the more carnivorous coastal populations are larger than those of interior populations. For example, Alaska Peninsula males weigh as much as 357 kg, while Mackenzie Mountains males average 148 kg (Schwartz et al., 2003), and barren-ground grizzlies are even smaller (Ferguson and McLoughlin, 2000). Elbroch (2006:85) records the upper intercanine width range (Tip) as 51.52 – 76.42 mm for males and 51.73 – 70.55 mm for females. Murmann et al. (2006: Table 16) list a combined Tip and MBH intercanine width of 3.4 – 9.6 cm.

The VZAP collection includes two grizzly bear skulls and mandibles: one is from an old adult male with a very large upper intercanine width of 91.31 mm (Tip) and 67.26 mm (MBH), while the other, from a smaller adult of unknown sex, measures 63.49 mm (Tip) and 41.39 mm (MBH). Following the same procedure used for the wolf and black bear, the old grizzly was imported into a shared platform with the Sadlermiut cranium for comparison. It was immediately clear that this individual was too large to make any of the paired lesions (Fig. 8c), which is unsurprising considering that the zygomatic breadth continues to increase with age in this species, even after maximum skull length is reached (Rausch, 1963; Zavatsky, 1976).

When the smaller grizzly also proved too large (Fig. 8d), we proceeded to assess whether an even smaller grizzly, akin to a barren-ground individual, could inflict any of the trauma. Unable to match even a small adult's dentition to the lesions, we reduced the scale of the virtual skull and mandible until they approximated those of a subadult, with no more success, establishing that the woman's injuries remained outside this species' range of morphological variability. We therefore conclude that while a large subadult or adult could cause substantial damage to a human skeleton, the grizzly's specific and distinct craniodental traits, particularly its comparatively broad and short rostrum, large but blunt canines, and tooth row spacing, do not match any of the cranial lesions.

Ursus maritimus (Polar Bear)

Even though polar bears are considered distinct from brown bears, this divergence is relatively recent, and the two species can interbreed and produce viable offspring (e.g., Kurtén, 1964; Doupé et al., 2007; Lindqvist et al., 2010; Hailer et al., 2012). The two continue to share aspects of their physiology, including very marked sexual dimorphism, heavy musculature, and large body size, although polar bears are on average the largest of the extant ursids (DeMaster and Stirling, 1981). Adult polar bear males weigh 420 – 500 kg, with some weighing more than 800 kg; adult females usually do not surpass 400 kg (Banfield, 1974; DeMaster and Stirling, 1981; Stirling and Derocher, 1990; Amstrup, 2003). We could find no published data on polar bear intercanine widths.

The sympagic polar bear is found throughout the northern circumpolar world and is a year-round resident of Hudson Bay and its islands (Banfield, 1974; Amstrup, 2003; Stirling, 2011). The polar bear's close association with sea ice is reflected in several physiological adaptations not seen in the grizzly bear (most are also tied to its hypercarnivorous diet): the teeth in particular have changed and include longer and more tapered canines, smaller premolars and molars, a larger diastema allowing deeper penetration of the canines when biting, a narrower palate, and molars better suited for shearing animal flesh than for processing tough vegetation. Additional changes include (but are not limited to) a long narrow head and muscular neck adapted for pulling subnivean seals through breathing holes and birth lairs, excellent eyesight, enhanced olfactory abilities, and shorter curved claws for gripping ice and prey (Kurtèn, 1964; DeMaster and Stirling, 1981; Amstrup, 2003; Sacco and Van Valkenburgh, 2004; Elbroch, 2006; Christiansen, 2008; Slater et al., 2010; Derocher and Lynch, 2012). *U. maritimus* digests fat more easily than other body tissues (Best, 1985), which perhaps explains why many bears maximize their caloric return by first eating the outer fatty layer before consuming underlying tissue (Stirling, 1974; Stirling and McEwan, 1975; Smith and Sjare, 1990).

We brought the complete skull and mandible of an adult female polar bear from VZAP into an interactive virtual environment with the Sadlermiut cranium, as we had done for the other candidate carnivores evaluated. It was immediately apparent that this bear's upper canines, with an intercanine width of 56.49 mm (Tip) or 39.91 mm (MBH), almost perfectly matched lesions i and iv (Fig. 9). Holding the upper canines in position, we virtually rotated the bear skull and mandible and human cranium while testing other possible paired lesions and suspected bite events, determining that the position of the cranial lesions matched not only the virtual polar bear's upper canines independently, but also the armature-constructed "mouth" in general. Such a close correspondence strongly suggests that a polar bear approximating the size of the VZAP adult female attacked the Sadlermiut woman.

RECONSTRUCTING A BITE SEQUENCE

Having identified the species and size of animal most probably responsible for the woman's trauma, we double-checked our identification of lesions i and iv as paired traumas by systematically repositioning and rotating both the human cranium and polar bear skull, using the armature to adjust the bear's mouth, ruling out any other possible configuration for the lesions. We then used the armature to open the bear's articulated jaw in order to determine where its lower canines should have contacted the woman during the bite event associated with lesions i and iv. Although the position of these injuries indicated that additional trauma should have occurred on the left side of the woman's maxilla or mandible (Fig. 9), careful examination of both the actual and the virtual crania revealed no evidence for such injury. Reconsidering the damage identified on the woman's post-cranial skeleton, we believe that the bear's lower canines did not contact the cranium because the woman appears to have thrown up her left arm in a protective act just before the bite labeled Bite A occurred. This action shielded the woman's face, but allowed the bear's lower left canine to bite into the arm near the elbow, causing the previously described puncture damage to the proximal radius.

FIG. 9. Assessing fit between paired lesions i and iv (Bite A) and the canines of an adult polar bear from the VZAP collection.

Further testing in the digital environment with the armature allowed us to match the location and spacing of cranial lesions against the VZAP polar bear's canines, permitting us to identify six additional bite events (Bites B – G, Fig. 10) and further confirm that a bear comparable in size to the virtual polar bear was most probably involved in the attack. We again stress that this process was exacting, with many false starts and backtracking; as with the bite involving cranial lesions i and iv (also the left radius), we sometimes found that all four canines did not impact the woman's cranium during specific contacts, meaning fewer than four lesions might account for one "bite." This does not necessarily mean that all canines were not involved; simply that some may have impacted only soft tissue, leaving no identifiable traces on the woman's skeleton.

Indeed, while theoretically there could be as many as 16 possible bites, one for each lesion, our goal was to determine the minimum number necessary to account for all of the traumas. To aid this process, we colour-coded each lesion as it was associated with a particular bite, eliminating it from consideration for the remaining contacts (except lesion xii, which is linked to two sequential events). We concluded that a minimum of seven "bites" are represented (Figs. 9 and 10). Using the position of the bites (which directly suggests the position of the bear and woman) and the occurrence of overlying or interrupted fracture lines,

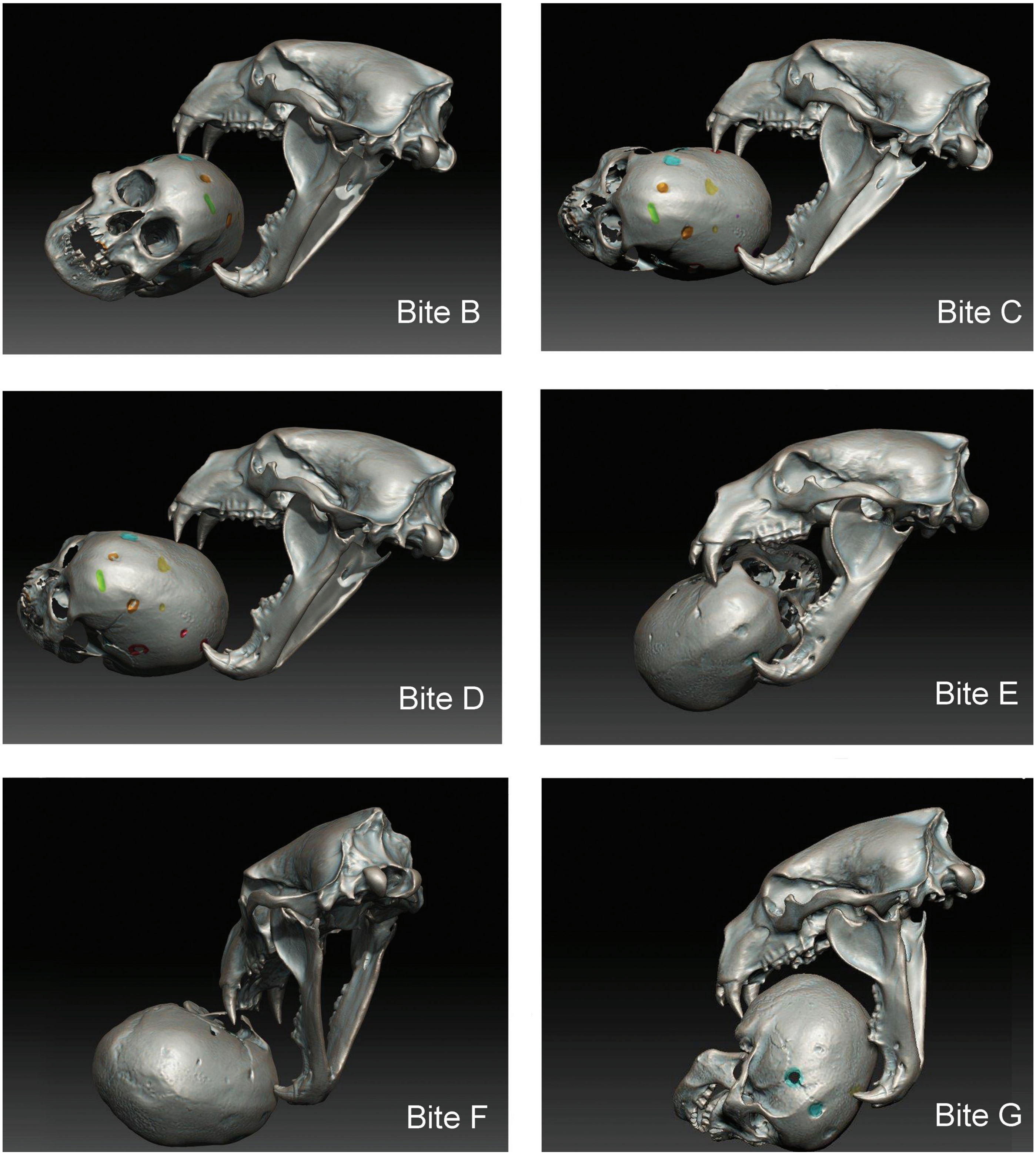

FIG. 10. The suggested sequence of six additional bites, reconstructed using an articulated polar bear skull and mandible from the VZAP collection.

we propose a possible bite sequence involving a minimal amount of movement between the bear and woman. It begins with the woman, likely crouching or kneeling, facing the bear before appearing to turn away. The proposed progression is Bite A (lesions i and iv, plus the left radius), Bite B (lesions vi and xiii), Bite C (lesions vii and xii), Bite D (also involving lesion xii, when the left upper canine rotated in place while the lower left canine made lesion ix), Bite E (lesions iii, x, and xi), Bite F (lesions v and xiv), and Bite G (lesions ii, viii, xv and xvi). This ordering is further contextualized in our discussion.

USING MODERN POLAR BEAR BEHAVIOUR TO UNDERSTAND PAST PREDATION ON HUMANS

Although uncommon, aggressive encounters between polar bears and humans do occur (Gjertz and Persen, 1987; Stenhouse et al., 1988; Herrero and Fleck, 1990; Floyd, 1999; Clark, 2003; Dyck, 2006; Towns et al., 2009). Of 20 injurious interactions analyzed by Herrero and Fleck (1990: Table 3), only three were motivated by defense of young; in contrast, 15 incidents were predacious and 13 of those involved the typically more aggressive male (Ramsay and Stirling, 1986; Dyck, 2006).

Examining polar bear-human incidents more generally, researchers have determined that hungry or less cautious bears investigating new potential food sources are most often implicated in antagonistic or threatening episodes (Stirling et al., 1977; Stirling and Latour, 1978; Lunn and Stirling, 1985; Stirling, 2011). In many of these cases, the bear was clearly displaying the same predatory behaviours, including stalking and the use of cover, that it would employ when hunting marine and terrestrial species (e.g., Stirling, 1974; Miller and Wooldridge, 1983; Herrero and Fleck, 1990; Derocher et al., 2000; Brook and Richardson, 2002). This sets the polar bear apart from the grizzly, for which at least half of all aggressive interactions are unintentional and prompted by surprise, typically because a person appeared without warning at close range and was identified as a threat by the bear (Herrero, 1970, 1976). In such circumstances, a threatened grizzly might attempt to remove the perceived danger by initiating an attack of relatively short duration, which typically leaves the human mauled but alive.

In contrast, while episodes of physical contact between polar bears and humans are much rarer, *U. maritimus* uses surprise as a key part of its hunting strategy. As Stirling (2011:55) has observed, "the victim is often unaware of the bear's presence until it appears at close range," further remarking that "a polar bear attack on a human usually ends only when one of them is dead." Derocher and Lynch (2012) note that polar bears can reach more than 32 km/h on flat ice, although they can quickly overheat (Best, 1982). When this speed is factored in with a bear's agility, strength, and specially adapted teeth and claws, a victim typically has little chance of survival once contact commences (e.g., Herrero and Fleck, 1990; Derocher and Lynch, 2012).

Although records have been variously kept regarding the specific polar bears involved (Gjertz and Persen, 1987; Stenhouse et al., 1988; Clark, 2003; Dyck, 2006), there is a clear demographic breakdown for so-called "problem" individuals. Subadult bears more than two but less than six years of age are most frequently implicated in aggressive encounters, with males significantly outnumbering females (Gjertz and Persen, 1987; Stenhouse et al., 1988; Herrero and Fleck, 1990; Lee and Taylor, 1994; Dyck, 2006; Towns et al., 2009; Stirling, 2011). These are the bears who are newly independent of their mothers and for whom the necessary hunting skills are not fully developed (Stirling, 1974; Stirling and Latour, 1978; Derocher and Stirling, 1996). They are also physically immature, typically only weighing up to 180 kg, meaning they often are too small to defend a kill from larger marauding adults (Banfield, 1974; DeMaster and Stirling, 1981; Gjertz and Persen, 1987; Amstrup, 2003). If conditions are especially unfavourable, these smaller bears may be compelled to take greater risks and consider any prospective food sources or chance starvation (Derocher and Stirling, 1996; Rockwell and Gormezano, 2009; Stirling, 2011), especially during the ice-free period when bears are most nutritionally stressed and when the majority of documented encounters occur (Stenhouse et al., 1988; contra Gjertz and Persen 1987; Clark, 2003).

Southampton Island has historically supported large numbers of bears because it is both a locus for maternal dens (Harington, 1968) and a summer retreat during the open water months (Lunn and Stenhouse, 1987; Lunn et al., 1987; Stenhouse and Lunn, 1987). Bears are especially common on the southern coast near the end of the ice-free period because this is where stable sea ice first develops (Shannon and Freeman, 2009). The location of this seasonal bear refugium overlaps with the densest area of Sadlermiut settlement, and this overlap, along with the Sadlermiut's overwhelmingly marine-focused economy (Mathiassen, 1927; Collins, 1956, 1957, 1958; Taylor, 1960; Clark, 1980), potentially put the two in direct competition with each other, increasing the likelihood that they would encounter one another on the land and sea. That this at least occasionally occurred is clear from contemporary sources, which reveal that while the Sadlermiut frequently pursued polar bears, they were also hunted and were "very much in fear" of them (Comer, in Boas 1907:474; also Hall, 1879:104).

DISCUSSION

Our analysis indicates that a polar bear whose size is consistent with an adult female or subadult male was most probably responsible for the traumatic injuries on the Sadlermiut woman's skeletal remains. The sequence of individual bites that we determined from fracture patterns and positioning suggests that the woman may have been surprised by the bear, whose sudden appearance caused her to raise her left arm to protect her head and face from a frontal attack (Bite A). Three additional bites (Bites B–D) followed the first and occurred along the top and back of the cranium; these appear to have involved less force, perhaps because they occurred quickly as the woman instinctively turned from the bear while assuming a crouched position, possibly struggling to escape. A fifth contact (Bite E), administered while the bear and woman again faced one another, was catastrophic: it punctured and fractured her temporal and parietal bones and depressed them into the cranial vault. Another bite (F), identified on the left front side of the cranium, may have broken the zygomatic arch. The final bite (G) was to the back of the woman's head; the location of the lesions suggests that the woman was supine and face down, possibly as the bear dragged her, as suggested by the nature of lesions xv and xvi.

We cannot determine when during the attack the woman's femurs were damaged, although the diaphyses were clearly broken while the woman faced away from the bear (possibly before Bite E). The order of the bites and the woman's position when the last bite was administered suggest an attack motivated by predation rather than defense, consistent with the majority of modern polar bear–human physical interactions. The many cranial wounds indicate that the bear focused its attention on this part of the body, a typical hunting strategy, although the sheer number of individually non-fatal contacts may imply an inexperienced predator. Alternatively, the bear may have been confused at the last moment by unanticipated sensory information (e.g., Stirling, 2011:56–57), realizing it was dealing with a prey animal other than what it expected and delaying an immediately fatal bite.

Unlike the cases reported by Merbs (1989, 1997), this case shows no evidence that the bear consumed any part of this woman. Indeed none of the injuries we documented appear to have been immediately fatal, although the woman was very gravely injured and certainly died as a result of the attack. While it is likely that someone at Native Point cared for the woman before her death, the location of her remains on the outskirts of the village in what Collins (1954–55b) identified as a disused tent suggests that her caregivers did not wish to place her inside an occupied dwelling. This was probably because the Sadlermiut, like other Inuit, maintained a taboo against deaths inside inhabited dwellings (e.g., Boas, 1888, 1907; Comer, 1910; Rasmussen, 1929, 1932). Groups typically went to great lengths to prevent such a calamity, as it meant the dwelling and its contents had to be abandoned. When the woman succumbed to her injuries, the tent was once more abandoned and became her de facto grave.

CONCLUSIONS

This study introduces a unique new method that uses VZAP in combination with other emerging digital technologies to facilitate the investigation of skeletal trauma. This approach is significant because only four institutions in North America currently curate comprehensive Arctic vertebrate reference collections (Betts et al., 2011). Considering that our study required us to test the craniodental morphology of multiple differently sized individuals per taxon against the Sadlermiut woman's cranial lesions, access to sufficiently complete extant osteological collections potentially posed a real obstacle to analysis. Fortunately, the intersection of two separate projects, the creation of a digital collection associated with the ongoing repatriation of Inuit human remains at the CMH, and the online VZAP initiative, allowed us to overcome this obstacle. By partnering the two collections, we were able to conduct direct virtual comparisons between the woman's cranial trauma and the complete skulls and mandibles of the four chosen Arctic taxa in a manner not previously attempted.

Our method offers two additional advantages: human and animal specimens were not subjected to the risks associated with transportation, and direct contact between the fragile skeletons (an unavoidable requirement if comparing lesions against carnivore teeth using a more traditional, hands-on approach) was not necessary. In this case, we were able to evaluate our suspicion that the force responsible for the skeletal damage was neither post-mortem nor caused by a firearm, as originally suggested by the excavator, but instead evidenced a fatal perimortem encounter with a large-bodied animal, most probably a polar bear. This analysis exposes not only how much potentially remains to be learned from extant collections as new technologies and analytical techniques are developed and refined, but also how 3D visualization technology and virtual museum collections can be rallied to create novel hybrid tools useful in forensic studies.

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REFERENCES

Amstrup, S.C. 2003. Polar bear (*Ursus maritimus*). In: Feldhamer, G.A., Thompson, B.C., and Chapman, J.A., eds. Wild mammals of North America: Biology, management, and conservation, 2nd ed. Baltimore, Maryland: The Johns Hopkins University Press. 587–610.

Banfield, A.W.F. 1974. The mammals of Canada. Toronto: University of Toronto Press.

Behrensmeyer, A.K. 1978. Taphonomic and ecologic information from bone weathering. Paleobiology 4(2):150–162. http://www.jstor.org/stable/2400283

Bergman, D.L., Sparklin, W., Carrillo, C.D., Schmidt, J.A., III, Bender, S., and Breck, S.W. 2010. Depredation investigation: Using canine spread to identify the predator species. In: Timm, R.M., and Fagerstone, K.A., eds. Proceedings of the 24th Vertebrate Pest Conference, 22–25 February 2010, Sacramento, California. Davis: University of California, Davis. 304–307.

Bernitz, H., Bernitz, Z., Steenkamp, G., Blumenthal, R., and Stols, G. 2012. The individualisation of a dog bite mark: A case study highlighting the bite mark analysis, with emphasis on differences between dog and human bite marks. International Journal of Legal Medicine 126(3):441–446. http://dx.doi.org/10.1007/s00414-011-0575-4

Berryman, H.E., and Haun, S.J. 1996. Applying forensic techniques to interpret cranial fracture patterns in an archaeological specimen. International Journal of Osteoarchaeology 6(1):2–9. http://dx.doi.org/10.1002/(SICI)1099-1212(199601)6:1<2::AID-OA244>3.0.CO;2-R

Berryman, H.E., and Symes, S.A. 1998. Recognizing gunshot and blunt cranial trauma through fracture interpretation. In: Reichs, K.J., ed. Forensic osteology: Advances in the identification of human remains, 2nd ed. Springfield, Illinois: Charles C. Thomas Publisher, Ltd. 333–352.

Best, R.C. 1982. Thermoregulation in resting and active polar bears. Journal of Comparative Physiology 146(1):63–73. http://dx.doi.org/10.1007/BF00688718

———. 1985. Digestibility of ringed seals by the polar bear. Canadian Journal of Zoology 63(5):1033–1036. http://dx.doi.org/10.1139/z85-155

Betts, M.W., Maschner, H.D.G., Schou, C.D., Schlader, R., Holmes, J., Clement, N., and Smuin, M. 2011. Virtual zooarchaeology: Building a web-based reference collection of northern vertebrates for archaeofaunal research and collection. Journal of Archaeological Science 38(4):755–762. http://dx.doi.org/10.1016/j.jas.2010.06.021

Bird, J. 1953. Southampton Island. Department of Mines and Technical Surveys. Ottawa: Queen's Printer.

Boas, F. 1888. The Central Eskimo. In: 6th Annual Report of the Bureau of American Ethnology for the Years 1884–1885. Washington, D.C.: Government Printing Office. 399–669.

———. 1907. Second report on the Eskimo of Baffin Land and Hudson Bay. Bulletin 15, article 2. New York: American Museum of Natural History.

Boaz, N.T., Ciochon, R.L., Xu, Q., and Liu, J. 2000. Large mammalian carnivores as a taphonomic factor in the bone accumulation at Zhoukoudian. Acta Anthropologica Sinica 19 (Suppl.):224–234.

Brain, C.K. 1981. The hunters or the hunted? An introduction to African cave taphonomy. Chicago: University of Chicago Press.

Brook, R.K., and Richardson, E.S. 2002. Observations of polar bear predatory behaviour toward caribou. Arctic 55(2):193–196. http://dx.doi.org/10.14430/arctic703

Buikstra, J.E., and Ubelaker, D.H. 1994. Standards for data collection from human skeletal remains. Proceedings of a seminar at the Field Museum of Natural History. Fayetteville: Arkansas Archaeological Survey Research Series No. 44.

Christiansen, P. 2007. Evolutionary implications of bite mechanics and feeding ecology in bears. Journal of Zoology 272(4):423–443. http://dx.doi.org/10.1111/j.1469-7998.2006.00286.x

———. 2008. Feeding ecology and morphology of the upper canines in bears (Carnivora: Ursidae). Journal of Morphology 269(7):896–908. http://dx.doi.org/10.1002/jmor.10643

Christiansen, P., and Wroe, S. 2007. Bite forces and evolutionary adaptations to feeding ecology in carnivores. Ecology 88(2):347–358. http://dx.doi.org/10.1890/0012-9658(2007)88[347:BFAEAT]2.0.CO;2

Clark, B. 1980. The Lake site (KkHh-2), Southampton Island, N.W.T. and its position in Sadlermiut prehistory. Canadian Journal of Archaeology 4:53–81.

Clark, D. 2003. Polar bear–human interactions in Canadian national parks, 1986–2000. Ursus 14(1):65–71. http://www.jstor.org/stable/3872958

Collins, H.B. 1954. Field notes, Southampton Island, 1954. Unpubl. ms. 1973. Available at the Canadian Museum of History, 100 Laurier St., Gatineau, Quebec K1A 0M8.

———. 1954–55a. List of Eskimo skeletal material from Native Point and vicinity, Southampton Island, N.W.T. Unpubl. ms. 1970. Available at the Canadian Museum of History, 100 Laurier St., Gatineau, Quebec K1A 0M8.

———. 1954–55b. Field notes, Native Point, Southampton Island, 1954 and 1955. Unpubl. ms. 1974. Available at the Canadian Museum of History, 100 Laurier St., Gatineau, Quebec K1A 0M8.

———. 1955. Southampton Island 1955. Unpubl. ms. 1975. Available at the Canadian Museum of History, 100 Laurier St., Gatineau, Quebec K1A 0M8.

———. 1956. Vanished mystery men of Hudson Bay. National Geographic 110(5):669–687.

———. 1957. Archaeological investigations on Southampton and Walrus Islands, N.W.T. Annual Report of the National Museum of Canada for 1955–56. National Museum of Canada Bulletin 147:22–61.

———. 1958. Present status of the Dorset problem. Proceedings of the 32nd International Congress of Americanists. 557–560.

Coltrain, J.B., Hayes, M.G., and O'Rourke, D.H. 2004. Sealing, whaling, and caribou: The skeletal isotope chemistry of Eastern Arctic foragers. Journal of Archaeological Science 31(1):39–57. http://dx.doi.org/10.1016/j.jas.2003.06.003

Comer, G. 1910. A geographical description of Southampton Island and notes upon the Eskimo. Bulletin of the American Geographical Society 42(2):84–90.

De Giorgio, F., Rainio, J., Pascali, V.L., and Lalu, K. 2007. Bear attack—a unique fatality in Finland. Forensic Science International 173(1):64–67. http://dx.doi.org/10.1016/j.forsciint.2006.08.026

Delaney-Rivera, C., Plummer, T.W., Hodgson, J.A., Forrest, F., Hertel, F., and Oliver, J.S. 2009. Pits and pitfalls: Taxonomic variability and patterning in tooth mark dimensions. Journal of Archaeological Science 36(11):2597–2608. http://dx.doi.org/10.1016/j.jas.2009.08.001

DeMaster, D.P., and Stirling, I. 1981. *Ursus maritimus*. Mammalian Species 145. 7 p. http://dx.doi.org/10.2307/3503828

Derocher, A.E., and Lynch, W. 2012. Polar bears: A complete guide to their biology and behavior. Baltimore, Maryland: The John Hopkins University Press.

Derocher, A.E., and Stirling, I. 1996. Aspects of survival in juvenile polar bears. Canadian Journal of Zoology 74(7):1246–1252. http://dx.doi.org/10.1139/z96-138

Derocher, A.E., Wiig, Ø., and Bangjord, G. 2000. Predation of Svalberd reindeer by polar bears. Polar Biology 23(10):675–678. http://dx.doi.org/10.1007/s003000000138

Domínguez-Rodrigo, M., and Piqueras, A., 2003. The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviours. Journal of Archaeological Science 30(11):1385–1391.
http://dx.doi.org/10.1016/S0305-4403(03)00027-X

Doupé, J.P., England, J.H., Furze, M., and Paetkau, D. 2007. Most northerly record of a grizzly bear (*Ursus arctos*) in Canada: Photographic and DNA evidence from Melville Island, Northwest Territories. Arctic 60(3):271–276.
http://dx.doi.org/10.14430/arctic219

Dyck, M.G. 2006. Characteristics of polar bears killed in defense of life and property in Nunavut, Canada, 1970–2000. Ursus 17(1):52–62.
http://dx.doi.org/10.2192/1537-6176(2006)17[52:COPBKI]2.0.CO;2

Elbroch, M. 2006. Animal skulls: A guide to North American species. Mechanicsburg, Pennsylvania: Stackpole Books.

Elton, C.S. 1954. Further evidence about the barren-ground grizzly bear in northeast Labrador and Quebec. Journal of Mammology 35(3):345–357.
http://dx.doi.org/10.2307/1375959

Ferguson, S.H., and McLoughlin, P.D. 2000. Effect of energy availability, seasonality, and geographic range on brown bear life history. Ecography 23(2):193–200.
http://dx.doi.org/10.1111/j.1600-0587.2000.tb00275.x

Floyd, T. 1999. Bear-inflicted human injury and fatality. Wilderness & Environmental Medicine 10(2):75–87.
http://dx.doi.org/10.1580/1080-6032(1999)010[0075:BIHIAF]2.3.CO;2

Freer, L. 2004. North American wild mammalian injuries. Emergency Medicine Clinics of North America 22(2):445–473.
http://dx.doi.org/10.1016/j.emc.2004.01.008

George, J.C., Philo, L.M., Hazard, K., Withrow, D., Carroll, G.M., and Suydam, R. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort Seas stock. Arctic 47(3):247–255.
http://dx.doi.org/10.14430/arctic1295

Gignac, P.M., Makovicky, P.J., Erickson, G.M., and Walsh, R.P. 2010. A description of *Deinonychus antirrhopus* bite marks and estimates of bite force using tooth indentation simulations. Journal of Vertebrate Paleontology 30(4):1169–1177.
http://dx.doi.org/10.1080/02724634.2010.483535

Gjertz, I., and Persen, E. 1987. Confrontations between humans and polar bears in Svalbard. Polar Research 5(2):253–256.
http://dx.doi.org/10.1111/j.1751-8369.1987.tb00626.x

Glass, R.T., Jordan, F.B., and Andrews, E.E. 1975. Multiple animal bite wounds: A case report. Journal of Forensic Sciences 20(2):305–314.

Hailer, F., Kutschera, V.E., Hallström, B.M., Klassert, D., Fain, S.R., Leonard, J.A., Arnason, U., and Janke, A. 2012. Nuclear genomic sequences reveal that polar bears are an old and distinct bear lineage. Science 336(6079):344–347.
http://dx.doi.org/10.1126/science.1216424

Hall, C.F. 1879. Narrative of the second Arctic expedition made by Charles F. Hall: His voyage to Repulse Bay, sledge journeys to the Straits of Fury and Hecla and to King William's Land, and residence among the Eskimos, during the years 1864–'69. Washington, D.C.: Government Printing Office.

Harington, C.R. 1968. Denning habits of the polar bear (*Ursus maritimus* Phipps). Canadian Wildlife Service Report Series No. 5. Ottawa: Canadian Wildlife Service.

Harington, C.R., Macpherson, A.H., and Kelsall, J.P. 1962. The barren ground grizzly bear in northern Canada. Arctic 15(4):294–298.
http://dx.doi.org/10.14430/arctic3584

Herrero, S. 1970. Human injury inflicted by grizzly bears. Science 170(3958):593–598.
http://dx.doi.org/10.1126/science.170.3958.593

———. 1976. Conflicts between man and grizzly bears in the national parks of North America. International Conference on Bear Research and Management 3:121–145.

———. 1985. Bear attacks: Their causes and avoidance. New York: Lyons & Burford.

Herrero, S., and Fleck, S. 1990. Injury to people inflicted by black, grizzly or polar bears: Recent trends and new insights. Ursus 8(1):25–32.

Herrero, S., and Higgins, A. 1995. Fatal injuries inflicted to people by black bears. In: Auger, J., and Black, H.L., eds. Human-black bear interactions. Proceedings of the Fifth Western Black Bear Workshop, 22–25 February 1994. Provo, Utah: Brigham Young University Press. 75–81.

Kress, T.A., Porta, D.J., Snider, J.N., Fuller, P.M., Psihogios, J.P., Heck, W.L., Frick, S.J., and Wasserman, J.F. 1995. Fracture patterns of human cadaver long bones. Proceedings of the 1995 International IRCOBI Conference on the Biomechanics of Impact, 13–15 September 1995, Brunnen, Switzerland. 155–169.

Kurtén, B. 1964. The evolution of the polar bear *Ursus maritimus* Phipps. Acta Zoologica Fennica 108. 30 p.

Kuzminsky, S.C., and Gardiner, M.S. 2012. Three-dimensional scanning: Potential uses for museum conservation and scientific research. Journal of Archaeological Science 39(8):2744–2751.
http://dx.doi.org/10.1016/j.jas.2012.04.020

Larivière, S. 2001. *Ursus americanus*. Mammalian Species 647. 11 p.
http://dx.doi.org/10.1644/1545-1410(2001)647<0001:UA>2.0.CO;2

Lee, J., and Taylor, M. 1994. Aspects of the polar bear harvest in the Northwest Territories, Canada. International Conference on Bear Research and Management 9(1):237–243.

Lindqvist, C., Schuster, S.C., Sun, Y., Talbot, S.L., Qi, J., Ratan, A., Tomsho, L.P., et al. 2010. Complete mitochondrial genome of a Pleistocene jawbone unveils the origin of the polar bear. Proceedings of the National Academy of Sciences 107(11):5053–5057.
http://dx.doi.org/10.1073/pnas.0914266107

Loring, S., and Spiess, A.S. 2007. Further documentation supporting the former existence of grizzly bears (*Ursus arctos*) in northern Quebec-Labrador. Arctic 60(1):7–16.
http://dx.doi.org/10.14430/arctic260

Lovell, N.C. 1997. Trauma analysis in paleopathology. American Journal of Physical Anthropology 104(Suppl. 25):139–170. http://dx.doi.org/10.1002/(SICI)1096-8644(1997)25+<139::AID-AJPA6>3.0.CO;2-#

Lowry, D., De Castro, A.L.F., Mara, K., Whitenack, L.B., Delius, B., Burgess, G.H., and Motta, P. 2009. Determining shark size from forensic analysis of bite damage. Marine Biology 156(12):2483–2492. http://dx.doi.org/10.1007/s00227-009-1273-3

Lunn, N.J., and Stenhouse, G.B. 1987. Foxe Basin polar bear research program: 1985 field report. Manuscript Report 17. Rankin Inlet: Department of Renewable Resources, Government of the NWT.

Lunn, N.J., and Stirling, I. 1985. The significance of supplemental food to polar bears during the ice-free period of Hudson Bay. Canadian Journal of Zoology 63(10):2291–2297. http://dx.doi.org/10.1139/z85-340

Lunn, N.J., Gray, L., Taylor, M.K., and Lee, J. 1987. Foxe Basin polar bear research program: 1986 field report. Manuscript Report 18. Rankin Inlet: Department of Renewable Resources, Government of the NWT.

Manning, T.H. 1942. Remarks on the physiography, Eskimo, and mammals of Southampton Island. Canadian Geographic Journal 24(1):17–33.

Marsh, D.B. 1976. The stone winter houses of the Sadlermiut. The Beaver 307(3):36–39.

Mathiassen, T. 1927. Archaeology of the Central Eskimos I: Descriptive part. Report of the Fifth Thule Expedition, 1921–24, Vol. 4(1). Copenhagen: Gyldendalske Boghandel, Nordisk Forlag.

Merbs, C.F. 1989. Trauma. In: İşcan, M.Y. and Kennedy, K.A.R., eds. Reconstruction of life from the skeleton. New York: Wiley-Liss. 161–189.

———. 1997. Eskimo skeleton taphonomy with identification of possible polar bear victims. In: Haglund, W.D., and Sorg, M.H., eds. Forensic taphonomy: The postmortem fate of human remains. Boston, Massachusetts: CRC Press. 249–262.

Miller, G.D., and Wooldridge, D.R. 1983. Small game hunting behaviour of polar bears, *Ursus maritimus*. Canadian Field-Naturalist 97(1):93–94.

Miller, M., and Miller, J.H. 1972. Orthopaedics and accidents. London: The English Universities Press.

Mulders, R. 1997. Geographic variation in the cranial morphology of the wolf (*Canis lupus*) in northern Canada. MSc thesis, Laurentian University, Sudbury, Ontario.

Murmann, D.C., Brumit, P.C., Schrader, B.A., and Senn, D.R. 2006. A comparison of animal jaws and bite mark patterns. Journal of Forensic Sciences 51(4):846–860. http://dx.doi.org/10.1111/j.1556-4029.2006.00166.x

Nambiar, P., Brown, K.A., and Bridges, T.E. 1996. Forensic implications of the variation in morphology of marginal serrations on the teeth of the great white shark. Journal of Forensic Odonto-Stomatology 14(1):2–8.

Niven, L., Steele, T.E., Finke, H., Gernat, T., Hublin, J.-J. 2009. Virtual skeletons: Using a structured light scanner to create a 3D faunal comparative collection. Journal of Archaeological Science 36(9):2018–2023. http://dx.doi.org/10.1016/j.jas.2009.05.021

Nowak, R.M. 1983. A perspective on the taxonomy of wolves in North America. In: Carbyn, L.N., ed. Wolves in Canada and Alaska: Their status, biology, and management. Ottawa: Canadian Wildlife Report Series No. 45. 10–19.

Ortner, D.J., and Putschar, W.G.J. 1985. Identification of pathological conditions in human skeletal remains. Smithsonian Contributions to Anthropology No. 28. Washington, D.C.: Smithsonian Institution Press.

Paquet, P.C., and Carbyn, LN. 2003. Gray wolf (*Canis lupus* and allies). In: Feldhamer, G.A., Thompson, B.C., and Chapman, J.A., eds. Wild mammals of North America: Biology, management, and conservation, 2nd ed. Baltimore, Maryland: The Johns Hopkins University Press. 482–510.

Passalacqua, N.V., and Fenton, T.W. 2012. Developments in skeletal trauma: Blunt-force trauma. In: Dirkmaat, D.C., ed. A companion to forensic anthropology. Oxford: Wiley-Blackwell. 400–411. http://dx.doi.org/10.1002/9781118255377.ch19

Pelton, M.R. 2003. Black bear (*Ursus americanus*). In: Feldhamer, G.A., Thompson, B.C., and Chapman, J.A., eds. Wild mammals of North America: Biology, management, and conservation, 2nd ed. Baltimore, Maryland: The Johns Hopkins University Press. 547–555.

Ramsay, M.A., and Stirling, I. 1986. On the mating system of polar bears. Canadian Journal of Zoology 64(10):2142–2151. http://dx.doi.org/10.1139/z86-329

Rasmussen, K. 1929. Intellectual culture of the Iglulik Eskimos. Report of the Fifth Thule Expedition, 1921–24, Vol. 7(2). Copenhagen: Gyldendalske Boghandel, Nordisk Forlag.

———. 1932. Intellectual culture of the Copper Eskimos. Report of the Fifth Thule Expedition, 1921–24, Vol. 9. Copenhagen: Gyldendalske Boghandel, Nordisk Forlag.

Rausch, R.L. 1963. Geographic variation in size in North American brown bears, *Ursus arctos* L., as indicated by condylobasal length. Canadian Journal of Zoology 41(1):33–45. http://dx.doi.org/10.1139/z63-005

Rockwell, R.F., and Gormezano, L.J. 2009. The early bear gets the goose: Climate change, polar bears and lesser snow geese in western Hudson Bay. Polar Biology 32(4):539–547. http://dx.doi.org/10.1007/s00300-008-0548-3

Rockwell, R.F., Gormezano, L., and Hedman, D. 2008. Grizzly bears, *Ursus arctos*, in Wapusk National Park, northeastern Manitoba. Canadian Field-Naturalist 122(4):323–326.

Rollins, C.E., and Spencer, D.E. 1995. A fatality and the American mountain lion: Bite mark analysis and profile of the offending lion. Journal of Forensic Sciences 40(3):486–489.

Ross, W.G. 1977. Whaling and the decline of Native populations. Arctic Anthropology 14(2):1–8. http://www.jstor.org/stable/40315906

Sacco, T., and Van Valkenburgh, B. 2004. Ecomorphological indicators of feeding behaviour in the bears (Carnivora: Ursidae). Journal of Zoology 263(1):41–54.
http://dx.doi.org/10.1017/S0952836904004856

Sauer, N.J. 1998. The timing of injuries and manner of death: Distinguishing among antemortem, perimortem, and postmortem trauma. In: Reichs, K.J., ed. Forensic osteology: Advances in the identification of human remains, 2nd ed. Springfield, Illinois: Charles C. Thomas Publisher, Ltd. 321–332.

Schwartz, C.C., Miller, S.D., and Haroldson, M.A. 2003. Grizzly bear (*Ursus arctos*). In: Feldhamer, G.A., Thompson, B.C., and Chapman, J.A., eds. Wild mammals of North America: Biology, management, and conservation, 2nd ed. Baltimore, Maryland: The Johns Hopkins University Press. 556–586.

Shannon, K.A., and Freeman, M.M.R. 2009. Inuit observations of polar bears in Salliq/Coral Harbour, Nunavut, and the management of the conservation hunt. In: Freeman, M.M.R., and Foote, L., eds. Inuit, polar bears, and sustainable use: Local, national, and international perspectives. Occasional Publication No. 61. Edmonton: CCI Press. 39–50.

Shields, L.B.E., Bernstein, M.L., Hunsaker, J.C., III, and Stewart, D.M. 2009. Dog bite-related fatalities: A 15-year review of Kentucky medical examiner cases. American Journal of Forensic Medicine and Pathology 30(3):223–230.
http://dx.doi.org/10.1097/PAF.0b013e3181a5e558

Slater, G.J., Figueirido, B., Louis, L., Yang, P., and Van Valkenburgh, B. 2010. Biomechanical consequences of rapid evolution in the polar bear lineage. PLoS ONE 5(11): e13870.
http://dx.doi.org/10.1371/journal.pone.0013870

Smith, T.G., and Sjare, B. 1990. Predation of belugas and narwhals by polar bears in nearshore areas of the Canadian High Arctic. Arctic 43(2):99–102.
http://dx.doi.org/10.14430/arctic1597

Spiess, A.S. 1976. Labrador grizzly (*Ursus arctos* L.): First skeletal evidence. Journal of Mammology 57(4):787–790.
http://dx.doi.org/10.2307/1379460

Spiess, A.S., and Cox, S. 1976. Discovery of the skull of a grizzly bear in Labrador. Arctic 29(4):194–200.
http://dx.doi.org/10.14430/arctic2804

Stenhouse, G.B., and Lunn, N.J. 1987. Foxe Basin polar bear research program: 1984 field report. Manuscript Report 16. Rankin Inlet: Department of Renewable Resources Government of the NWT.

Stenhouse, G.B., Lee, L.J., and Poole, K.G. 1988. Some characteristics of polar bears killed during conflicts with humans in the Northwest Territories, 1976–86. Arctic 41(4):275–278.
http://dx.doi.org/10.14430/arctic1732

Stirling, I. 1974. Midsummer observations on the behavior of wild polar bears (*Ursus maritimus*). Canadian Journal of Zoology 52(9):1191–1198.
http://dx.doi.org/10.1139/z74-157

———. 2011. Polar bears: The natural history of a threatened species. Markham, Ontario: Fitzhenry & Whiteside.

Stirling, I., and Derocher, A.E. 1990. Factors affecting the evolution and behavioral ecology of the modern bears. International Conference on Bear Research and Management 8:189–204.

Stirling, I., and Latour, P. 1978. Comparative hunting abilities of polar bear cubs of different ages. Canadian Journal of Zoology 56(8):1768–1772.
http://dx.doi.org/10.1139/z78-242

Stirling, I., and McEwan, E.H. 1975. The calorific value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behavior. Canadian Journal of Zoology 53(8):1021–1027.
http://dx.doi.org/10.1139/z75-117

Stirling, I., Jonkel, C., Smith, P., Robertson, R., and Cross, D. 1977. The ecology of the polar bear (*Ursus maritimus*) along the western coast of Hudson Bay, Canada. Canadian Wildlife Occasional Paper No. 33. 64 p.

Strait, S.G., and Smith, N.E. 2006. PaleoView3D: An interactive database of mammals from the Paleocene/Eocene boundary. Journal of Vertebrate Paleontology 26(3), Supplement 129A.

Sutcliffe, A.J. 1970. Spotted hyaena: Crusher, gnawer, digester and collector of bones. Nature 227(5263):1110–1113.
http://dx.doi.org/10.1038/2271110a0

Tate, J., and Pelton, M.R. 1983. Human-bear interactions in Great Smoky Mountains National Park. International Conference on Bear Research and Management 5:312–321.

Taylor, W.E., Jr. 1959. The mysterious Sadlermiut. The Beaver 290:26–33.

———. 1960. A description of Sadlermiut houses excavated at Native Point, Southampton Island, N.W.T. Bulletin 162. Ottawa: Annual Report of the National Museum of Canada. 53–100.

Taylor, W.E., Jr., and Emerson, J.N. 1954. Untitled: Field maps of archaeological sites at Native Point, Southampton Island, Nunavut. Unpubl. ms. William E. Taylor, Jr. fonds, Box 22B, files 14 and 15 available at the Canadian Museum of History, 100 Laurier St., Gatineau, Quebec K1A 0M8.

Towns, L., Derocher, A.E., Stirling, I., Lunn, N.J., and Hedman, D. 2009. Spatial and temporal patterns of problem polar bears in Churchill, Manitoba. Polar Biology 32(10):1529–1537.
http://dx.doi.org/10.1007/s00300-009-0653-y

Ubelaker, D.H., and Adams, B.J. 1995. Differentiation of perimortem and postmortem trauma using taphonomic indicators. Journal of Forensic Sciences 40(3):509–512.

VZAP (Virtual Zooarchaeology of the Arctic Project). 2014. Pocatello, Idaho: Informatics Research Institute, Idaho State University.
http://vzap.iri.isu.edu/

Walker, P.L. 2001. A bioarchaeological perspective on the history of violence. Annual Review of Anthropology 30:573–596.
http://dx.doi.org/10.1146/annurev.anthro.30.1.573

Weber, G.W., and Bookstein, F.L., 2011. Virtual anthropology: A guide to a new interdisciplinary field. New York: Springer.

Wheatley, B.P. 2008. Perimortem and postmortem bone fractures? An experimental study of fracture patterns in deer femora. Journal of Forensic Sciences 53(1):69–72.
http://dx.doi.org/10.1111/j.1556-4029.2008.00593.x

Wieberg, D.A.M., and Westcott, D.J. 2008. Estimating the timing of long bone fractures: Correlation between the postmortem interval, bone moisture content, and blunt force trauma fracture characteristics. Journal of Forensic Sciences 53(5):1028–1034. http://dx.doi.org/10.1111/j.1556-4029.2008.00801.x

Zavatsky, B.P. 1976. The use of the skull in age determination of the brown bear. International Conference on Bear Research and Management 4:275–279.