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ORIGINAL PAPER

Large carnivore attacks on hominins during the Pleistocene: a forensic approach with a Neanderthal example

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Abstract Interaction between hominins and carnivores has been common and constant through human evolution and generated mutual pressures similar to those present in worldwide modern human-carnivore conflicts. This current interaction is sometimes violent and can be reflected in permanent skeletal pathologies and other bone modifications. In the present paper, we carry out a survey of 124 forensic cases of dangerous human-carnivore encounters. The objective is to infer direct hominin-carnivore confrontation during the Pleistocene, which is important to understand behavioral changes during human evolution. In addition, the case of Neanderthals is analyzed in order to find evidence of past attacks using forensic observations. The results obtained pose that Neanderthals could potentially have been involved in dangerous encounters during the Pleistocene, validating our methodology to approach past attacks from a forensic perspective.

Keywords Carnivores · Interaction · Confrontation · Forensic medicine · Neanderthals

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Introduction

Predation is assumed to be a fundamental influence in the evolution of primate behavior (Cheney and Wrangham 1987). Consequently, deterrence of predation has been described as an element with a high sociobiological impact on the origin of the human condition (Fay et al. 1995). Brain (1981) once asked "Who killed the Australopithecines?" as he recognized that the interaction between hominins and carnivores had enormous potential for the study of human behavioral changes; he pointed out that humans could effectively handle these interactions simply by increased intelligence and development of technology (Brain 1981).

Research on direct confrontation between hominins and large carnivores is clearly important (Hart and Sussman 2011), and yet this subject has not been extensively explored, largely due to the difficulty of approaching the topic using only archaeology and/or paleoanthropology. Nevertheless, dangerous encounters between carnivores and archaic forms of genus *Homo* have been inferred (e.g., Brain 1981; Bunn and Ezzo 1993; Treves and Naughton-Treves 1999; Boaz et al. 2004; Baquedano et al. 2012). The interactions between hominins and large carnivores have occurred at high frequency and taken different forms that generated mutual pressures (Rosell et al. 2012). Scenarios emerging from these pressures include dependency (scavenging) (Binford 1989; Stiner 1994), confrontation (carnivore

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hunting) (Auguste 1995; Arribas et al. 1997; Tillet 2002; Pérez Ripoll et al. 2010), competition for the use of caves as dwellings (Blasco and Rosell 2009), and the exploitation of common prey (Pettitt 1997). One of the latest documented scenarios is domestication during the Late Pleistocene (Germonpré et al. 2013).

Today, similar pressures result globally in conflicts between different wild large carnivore species and humans (Treves and Karanth 2003; Pettigrew et al. 2012). For example, conflicts are mainly related with snow leopards (*Uncia uncia*), leopards (*Panthera pardus*), tigers (*Panthera tigris*), and Asian black bears (*Ursus thibetanus*) in Asia (e.g., Hussain 2003; Mishra 1997; Sekhar 1998; Dhar et al. 2008); lions (*Panthera leo*), African hunting dog (*Lycaon pictus*), and hyenas (*Crocuta crocuta*) in Africa (e.g., Patterson et al. 2004; Gusset et al. 2009; Kolowski and Holekamp 2006); wolves (*Canis lupus*), cougars (*Puma concolor*), and bears (*Ursus arctos horribilis*, *Ursus americanus*) in North America (e.g., Musiani et al. 2003; Conrad 1992; Herrero and Fleck 1990); jaguars (*Panthera onca*) and pumas (*Puma concolor*) in South America (e.g., Polisar et al. 2003; Mazzolli et al. 2002); dingoes (*Canis lupus dingo*) in Australia (e.g., Allen and Sparkes 2001); or brown bears (*Ursus arctos*) and wolves (*Canis lupus*) in Europe (e.g., Swenson et al. 1999; Linnell et al. 2002). The reasons for these conflicts are mainly associated with the similar resource use patterns of people and wild animals (Ahmed et al. 2012) and with their overlapping habitats (Agarwal and Mumtaz 2009). These conflicts have generated a rising incidence of attacks that constitute an increasingly serious form of human-wildlife confrontation conflict (e.g., Herrero and Higgins 2003; Conover 2008; Brown and Conover 2008; Neto et al. 2011), related to shrinking wild carnivore habitats (Skuja 2002), loss of their prey (Thakur et al. 2007), or wildlife hunting (Inskip and Zimmermann 2009). As such, they present a scenario of mutual pressures between humans and wildlife that may be comparable to the relationships that existed between large carnivores and hominins during the Pleistocene. Fossil humans could have been involved in direct confrontation scenarios (dangerous encounters) with large carnivores similar to those seen today, which then have the potential to provide insight into hominin behavior and even inferences regarding social organization (e.g., Dhar et al. 2008; Nabi et al. 2009a, b; Rasool et al. 2010).

For this reason, we carried out a forensic survey with the objective of developing a comparative methodology aimed at identifying direct confrontations between hominins and carnivores during the Pleistocene. An application example is provided for the case of Neanderthals as a proof of concept, as these hominins are assumed to be a human form that had a close relationship with large carnivores (e.g., Estévez 2004; Dusseldorp 2011).

Materials and methods

Forensic information of carnivore attacks on humans was obtained by carrying out an intensive bibliographic survey. The data selected were obtained in specialized medical journals involving forensic cases where victims and injuries caused by carnivores could be clearly documented. The carnivores selected were members of the ursid, felid, and canid families. Although few well-described forensic cases exist for hyenids, this carnivore is also included in our survey (except for statistical observations).

All information has been transferred to a database where individual characteristics of either the victims or the attacking carnivores can be examined. Each case has been individualized so specific aspects of the resulting injuries inflicted by the animals could be overviewed. All injuries (including bone damage and general body wounds) are clustered depending on their location in skeletal and body zones (Fig. 1). A total of 124 cases are studied, and of these, 92 are considered for the quantitative analysis as the damage can be isolated. All information related to each case is available as Online Resource Material (the forensic cases database is also related to the bibliographic list provided) (Online source 1 and 2).

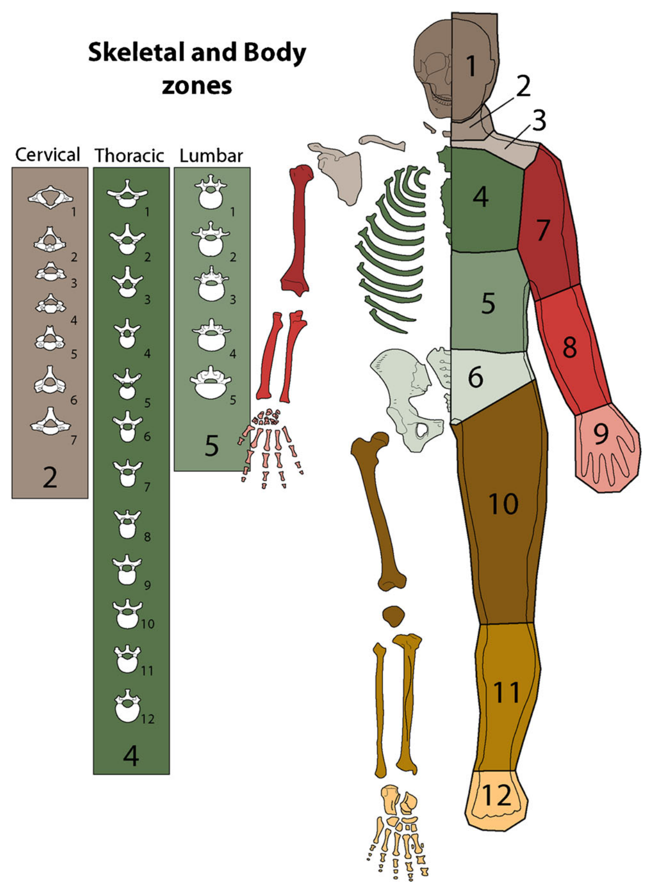

Fig. 1 Classification of skeletal and body zones used in the forensic survey

Observations are applied to the study of a Neanderthal bone fragment from the site of Cova Negra and to the register of traumatic lesions observable on the Neanderthal skeletons provided by Berger and Trinkaus (1995).

Forensic information is evaluated and patterns for each carnivore family in direct confrontation with humans are presented. A statistical approach is developed with the objective of observing major and minor injuries inflicted by each carnivore family. Nevertheless, our main interest is documentation of bone damage caused by all carnivores.

Results and discussion

Forensic survey of carnivore attacks to humans

Interaction between humans and wild animals has increased in recent decades (Ambarli and Bilgin 2008; Inskip and Zimmermann 2009), with a high proportion of these contacts being violent (Dhar et al. 2008). Carnivore attacks are characterized by the combined occurrence of injuries (including puncture wounds, lacerations, avulsions, and bone fractures (Baliga et al. 2012)), crushing, and penetrating trauma (Agarwal et al. 2011). Humans attacked by large carnivores are consequently at risk of suffering blunt and penetrating trauma caused by teeth, paws, and claws, which may lead to a local infection (Capitini et al. 2002; Kunimoto et al. 2004; Lehtinen et al. 2005; Türkmen et al. 2012) because wounds are often contaminated with a variety of pathogens (polymicrobial infection) such as *Pasturella multocida* and others (Kizer 1989; Isotalo et al. 2000; Linnell et al. 2002; Abrahamian and Goldstein 2011). Fatal attacks are common, especially in Africa and Asia (Conrad 1992), although many cases are reported in which victims survive a violent encounter with a carnivore (Agarwal et al. 2011). After a carnivore attack, victims may develop future specific pathologies such as arthritis (e.g., Burdge et al. 1985) or others (see Papadopoulos et al. 1999).

Although these are general trends observed in carnivore attacks, specific patterns can be identified in the forensic survey resulting from different carnivore families.

Ursidae

Direct confrontation between humans and bears is relatively common in different parts of the world (Lathrop 2007) and must be considered as either predatory or defensive (Herrero 1985; Herrero and Fleck 1990). Subspecies involved in these dangerous encounters are the black bear (*Ursus americanus*) (Murad and Boddy 1987), grizzly bear (*Ursus arctos horribilis*) (Cardall and Rosen 2003; Kunimoto et al. 2004), Asian black bear (*Ursus thibetanus*) (Agarwal et al. 2011), and less commonly the polar bear (*Ursus maritimus*) (Herrero and Fleck 1990) and brown bear (*Ursus arctos*) (Ambarli and Bilgin 2008). Although other subspecies are involved in attacks on humans (Rajpurohit and Krausman 2000; French 2001), only those cited here were studied in our forensic research. A total of 45 cases were analyzed.

In general, death is not common after a bear attack (Herrero and Fleck 1990), although serious injuries are generated by teeth, claws, and paws (French 2001). The bear attack pattern is one of the best studied in forensic medicine (e.g., Rasool et al. 2010). Bears tend to rear up on their hind legs and strike victims with their claws (Dhar et al. 2008). Biting the victim is also common, and a bear attack ends with different degrees of minor and major injuries, predominantly located in the upper half of the body (Dhar et al. 2008; Rasool et al. 2010; Agarwal et al. 2011; Baliga et al. 2012), especially in the head and face (Thakur et al. 2007).

The present observation of a total of 45 forensic cases is commensurate with this known attack pattern of bears. Figure 2a shows that within the 38 case studies with bone modifications, the main bone damage is located in the head zone (skull and mandible) and upper limbs (clavicle, humerus, radius, ulna, metacarpals, and hand phalanges). Bears tend to attack the victim's head, causing wounds and fractures in that zone, and humans react by protecting themselves with their arms, causing damage in that region. Long-bone diaphyseal linear, comminuted, and segmental fractures in the upper limb are not rare, and finger amputation is also common (Dhar et al. 2008). All these bony injuries are frequently associated with general soft-tissue wounds (Fig. 2b), as observed in other cases (Rasool et al. 2010). Therefore, bone modification after a bear attack would appear to occur in the body areas where other general non-bony wounds are inflicted by the animal.

Felidae

Feline attacks on humans reflect a predatory behavior in nearly all cases and follow the same pattern employed for predation on other large mammals (Cohle et al. 1990) in both wild and captive contexts (e.g., Hejna 2010). These encounters may not always be fatal for humans (Wright 1991), but due to large cats' attack pattern, they can result in very serious wounds caused by teeth and claws. Feline-human conflicts that end in dangerous encounters are increasingly common occurrences in different parts of the world (Nyhus and Tilson 2004; Inskip and Zimmermann 2009).

The felines (basically leopards (*Panthera pardus*) (Nabi et al. 2009a), jaguars (*Panthera onca*) (Neto et al. 2011), lions (*Panthera leo*) (Packer et al. 2005), tigers (*Panthera tigris*) (Langley and Hunter 2001), and cougars (*Puma concolor*)) attack humans in the same way in most cases. They carry out a solitary surprise attack motivated by a predatory behavior that can be stimulated by the quick erratic movements of the victim (e.g., jogging or running) (Conrad 1992; Rollins

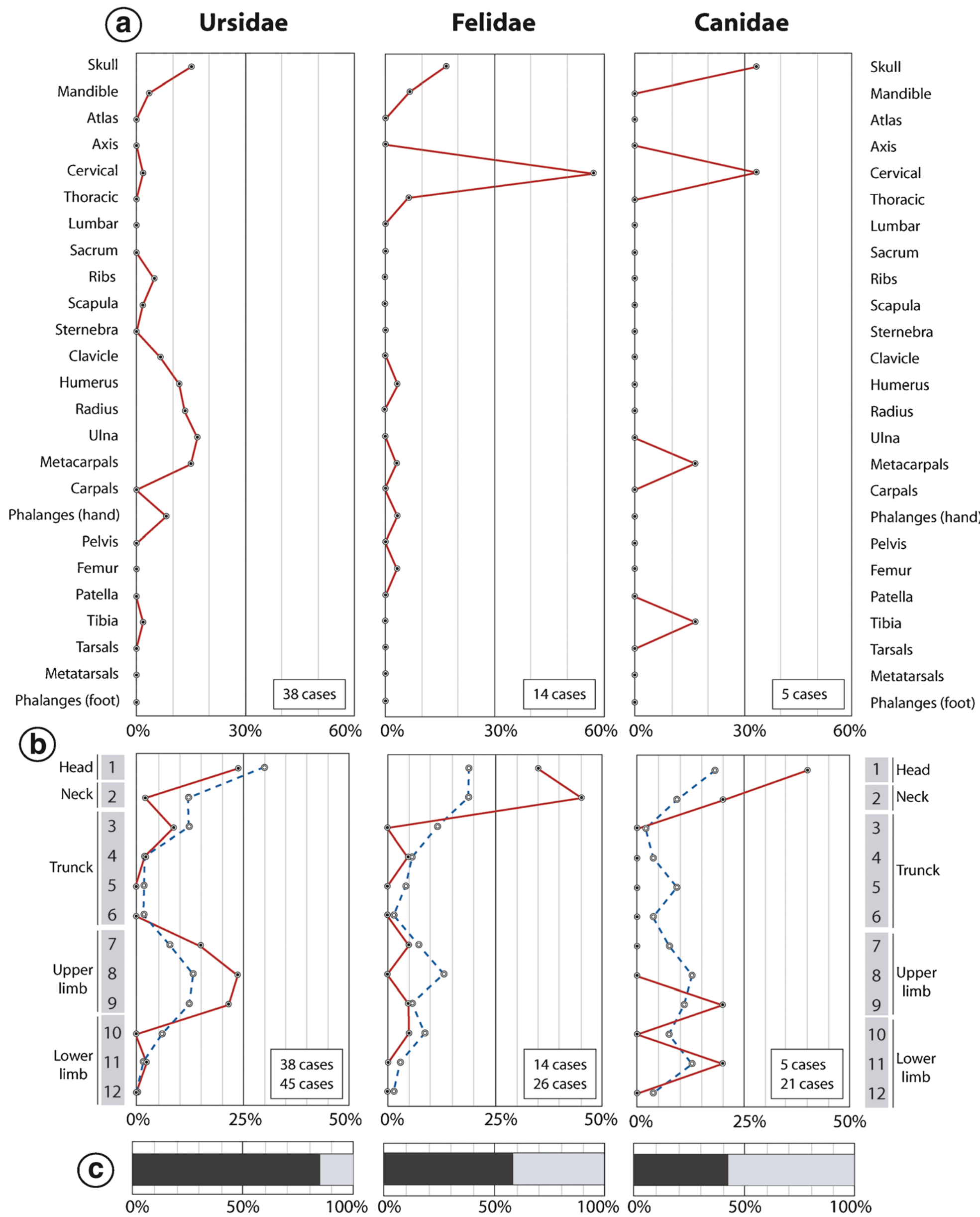

Fig. 2 Different patterns observed in carnivore attacks on humans by Ursidae, Felidae, and Canidae. **a** Bone damage (fractures/scores/punctures) observed in different cases for each skeletal element; **b** bone damage (fractures/scores/punctures) (*red line*) compared to general wounds (*blue dashed line*) in different cases for each body zone (*numbers* refer to Fig. 1); **c** average of bone damage compared to general wounds present in all cases. Source data provided as Online Resource Material (see Online Resource 1 and 2)

and Spencer 1995). Prey size is considered by felines in their solitary hunting (Atwood et al. 2007); thus, children are commonly attacked (Chum and Pui 2011). Felines rarely employ a head-on attack but prefer to approach the victim from behind or over the shoulder (Chapenoire et al. 2001). This results in major injuries in the head, nape, and neck regions, especially from penetrating bites that cause skull damage, cervical vertebral fractures, and/or damage to the anterior neck structure (Conrad 1992; Hejna 2010; Emami et al. 2012). Claws usually cause deep lacerations in the back. Other body regions, although represented by a minimum number of cases, can also be damaged (e.g., Burdge et al. 1985).

Bone damage on humans is basically defined by the feline's particular attack pattern. The predatory attack involves shaking the prey by the neck region (Bury et al. 2012), causing subsequent cervical lesions (Bock et al. 2000; Murphy et al. 2007; Nabi et al. 2009b; Chum and Pui 2011). This is usually defined by compound fractures of the cervical bodies (Chapenoire et al. 2001). Nevertheless, skull surface damage can also be caused by a big cat attack, and modifications such as scores, punctures, perforations, or cortical fractures caused by several bites may occur (Conrad 1992; Neto et al. 2011).

Our observations of 26 cases (14 with bone damage) corroborate previous studies, as bone damage is located in the head and neck area (Fig. 2a). Cervical vertebrae are the principal bone elements that suffer modification after a feline attack on a human. Other skeletal elements can also be affected, resulting from a defensive reaction by the person being attacked. Extremities are not the primary region where felines attack, but limbs are involved in rare cases (Conrad 1992) and exhibit comminuted bone fractures (Prayson et al. 2008) (Fig. 2).

Comparison of bone damage with other wounds not related with osteological modification by body zone (Fig. 2) shows good association in 26 cases. However, the upper limbs show more general wounds that do not include bone damage (specifically on the forearm). Wounds are located in this zone because the victims try to defend themselves from the attack with their arms.

Canidae

Currently, canids (essentially foxes, dingoes, wolves, and domestic dogs) account most frequently for cases of animal-related fatalities, with a very high number of attacks on humans (see Langley 2005). Our interest in canid-related fatalities was restricted to canid pack attacks and to single wild wolf attacks. Due to their ethology, most canids develop group hunting (Borchelt et al. 1983), and therefore, a single animal attack is somewhat rare in nature with wild specimens, although it happens (Linnell et al. 2002). In the present time, attacks by single canids on humans are rather more common (Weiss et al. 1998; Macbean et al. 2007) but are represented by *Canis familiaris*, and this is related to domestication and the consequences of living with these animals. Therefore, we have mainly focused on canid pack attacks, a situation where even domestic dogs, as social animals, have an inherent pack instinct that can cause them to become excited to a frenzy by the smell and taste of blood (Kneafsey and Condon 1995). Furthermore, since domestic dog pack attacks are very similar in pattern to those seen with wolf groups in the wild (Butler et al. 2011), they are also included in our survey.

Pack behavior will generate an attack pattern directed toward humans that consists of immobilizing the prey by striking at the limbs. Once the prey has been brought down, canids will attack all parts of the body (Fonseca and Palacios 2013), especially the head and neck area (Kneafsey and Condon 1995; Avis 1999; Linnell et al. 2002; Bury et al. 2012), followed by extremities (Wright 1990). Defensive marks can also appear on the upper and lower extremities (de Munnynck and van de Voorde 2002), and the victim's movements will simultaneously stimulate the attack (Lauridson and Myers 1993), even leading to amputation of portions of a limb (Avis 1999). Biting, clawing, and crushing forces to the head, neck, and hindquarters will produce a combination of wounds, described as punctures, lacerations, and avulsion of skin and soft tissue (Santoro et al. 2011). Bone damage also occurs to those zones (Bury et al. 2012). In the case of wolves, a predominance of injuries on the dorsal aspect of the body has been observed by Nabi et al. (2009a).

As with felines, canids select their prey by size; thus, children are very often targets of attacks (Fouriel and Cartilidge 1995). Because of a child's relatively soft and vulnerable skull, serious penetrating injuries of the cranium have been described (idem.).

A total of 21 cases have been analyzed; five were pack attacks. The canid collective attack strategy leads to the appearance of bone damage on different parts of the body such as the head (skull), the neck (cervical vertebrae), and the arms (metacarpal) and legs (tibia) (Fig. 2a).

Comparison of the body regions where bone damage appears with the location of general wounds (Fig. 2b) after a canid attack indicates that soft tissue injuries are not highly related with osteological modification. In this sense, a canid attack can generate serious wounds all over the body, especially in the trunk region (Nabi et al. 2009a), but this does not mean that bone damage is associated.

Hyenidae

Hyena attacks are not well reflected in forensic literature and thus are not included in the database and quantitative study of carnivore attack patterns. Nevertheless, this section has been added to illustrate that hyena attacks on humans are common today, just as they could have been in the past.

In Africa, hyenas coexist with humans at a high density in some countries (Yirga et al. 2012), and this situation may lead to dangerous encounters. In situations of hunger, hyenas can attack humans, perceiving small children and the elderly as vulnerable and easier prey (Brain 1981; Gade 2006). Nevertheless, although predatory attacks on people occur, hyenas much more commonly feed on humans by scavenging human tombs in cemeteries (Horwitz and Smith 1988; Yirga et al. 2012).

The scarcity of forensic literature on hyena attacks complicates any inference regarding an attack pattern toward humans. In spite of this situation, Mitchell et al. (2011) have recorded an attack on a 27-year-old female in Tanzania that reveals a probable pattern. In this case, a single hyena followed a pattern similar to the one employed by large cats, by attacking the head and neck region of the victim in an attempt to cause prey submission, and probably damaging the cervical spine zone (Mitchell et al. 2011). Although hyenas look like canids, genetically they are similar to felines, and in this sense, hyenas probably follow a similar pattern to that of one of the large cats (idem.)

This single case is not sufficient to infer a pattern, especially considering the pattern that hyenas follow to hunt other non-human mammals. Hyenas develop both lone and cooperative prey captures, although individual hunting has a much higher average of success (Watts and Holekamp 2007). The hyena hunting strategy reveals no significant preference for any species, and its behavioral opportunism allows the capture of anything it can overpower (Hayward 2006). Concerning prey size, a single hyena can capture a prey three times its body weight (Watts and Holekamp 2007).

Comparison between carnivore attacks

Similarities and differences both exist among carnivore attack patterns on humans. The evidence suggests that carnivores, when attacking humans, follow the same pattern as when hunting non-human prey (Herrero and Fleck 1990), especially if the attack is predatory. In these cases of attacks on humans, prey size again seems to be an important factor (Gade 2006) and is the reason why so many attacks on children have been recorded, especially in cases related with canids, felines, and even hyenas (e.g., Brain 1981; Conrad 1992; Fouriel and Cartilidge 1995; McKee 2003; Gade 2006).

The patterns followed by different carnivores when attacking humans permit the inference that carnivores can be grouped by family, rather than by species, depending on their ethology.

In general, carnivore attacks result in minor or major injuries, and only a relatively small proportion are fatal (Agarwal et al. 2011). However, this depends on the type of carnivore species. In the case of felines, the average number of attacks that lead to death is extremely high when compared to that of bears (Nabi et al. 2009a). This is probably because most cases related to felines are predatory (Neto et al. 2011), in contrast with bear attacks, which may often be related to defensive attacks (of their cubs or their territory) (Ambarli and Bilgin 2008). This is also something that can be inferred in the way a human is attacked. Ursids usually attack their victims from the front and as a dissuasive action (increased by a defensive reaction of the person, understood by the bear as a fighting response) (French 2001). Felines, on the other hand, tend to attack the victim/prey from the rear or over the shoulder (Chapenoire et al. 2001). The case of canids can be also classified as predatory or defensive attacks, and their attack pattern is similar to that of felines in the sense that they target the neck region, shaking the prey into submission (Bury et al. 2012). Nevertheless, the main difference is that canids usually attack in packs and therefore other pack members would help bring down the victim by biting the upper and lower extremities. As in bear attacks, death is not as common in canid attacks as it is following feline attacks.

One common feature of nearly all the carnivore attack cases, whether they are predatory or defensive, is that the victim was alone at the precise moment of the encounter with the attacking animal. Regarding the number of animals attacking, in the wild, felines (except for lion prides) and bears attack alone (although they can be accompanied by their cubs) and canids usually attack in packs.

The behavior of the animal attacking a human will determine the general injury pattern and, because the attack behavior is different for each carnivore family, the injury pattern will differ (Fig. 2). Among all carnivore families studied in the present paper, bears generate much more bone damage in cases of attacks (85 %), followed by felines (58 %), and canids (42 %) (Fig. 2c).

Our observations indicate that each carnivore has a different attack pattern that at the same time generates a different injury pattern, including differences in bone damage. These observations can be a general forensic base for differentiating between different carnivores responsible for an attack on a human, which may be difficult to identify on some occasions (Kiuchi et al. 2008).

Proof of concept: the Neanderthal case

The present paper has a clear forensic application and interest due to the characterization of the damage caused by carnivore attacks. Nevertheless, the aim of the research was to propose a methodology for collecting evidence for the reconstruction of past attacks. The comparison of a present scenario with a past one is valid because direct confrontation between hominins and carnivores during the Pleistocene, as in the present, involves mutual pressures derived from a conflictive relationship where common interests overlap (e.g., Schuette et al. 2013). Therefore, we use the modern relationship between humans and carnivores as a valid analogy (Treves and Naughton-Treves 1999) in order to approach the study of carnivore attacks on humans.

Providing evidence for this issue is not an easy task, and as a proof of concept, we have selected Neanderthals to validate our methodology. The Neanderthals developed intense interactions with large carnivores (Gamble 1993) due to mutual pressures arising from conflicts where competition was an inherent factor. Many pressures existed between top-carnivore Neanderthals (Bocherens et al. 2001) and carnivores, as both competed directly for resources (e.g., Dusseldorp 2011) and used the same caves (e.g., Straus 1982). The Neanderthals also hunted large carnivores (see Blasco et al. 2010). Moreover, it is not uncommon to find a good representation of carnivore remains in the archaeological sites where Neanderthals are documented, confirming their presence in the same territories (Straus 1992; Mussi 2001; Brugal and Fosse 2004). This scenario provides a context where direct confrontation existed, and therefore, it is an excellent case for applying our forensic observations in order to confirm past carnivore attacks on humans.

The Cova Negra (Spain) site, a well-known cave occupied during the Middle and Upper Pleistocene (Villaverde et al. 1996, 2004), contained 24 Neanderthal bone remains belonging to cranial, dental, and postcranial elements (Arsuaga et al. 2007). We have analyzed one of them (CN42174b), a cranial fragment belonging to the central part of a right parietal (idem.), due to its high similarity with the punctures present at cranial fragment SK-54 from Swartkrans (South Africa) described as a fossil reflecting a leopard attack to an

Australopithecus by Brain (1981). The parietal fragment bone CN42174b (Fig. 3) presents two measurable punctures on the exocranial surface, produced by a large carnivore (Fig. 3b, c), although the damage was interpreted as the action of a small carnivore by Arsuaga et al. (2007). The length and breadth have been measured and compared with data available from experimental samples provided by Domínguez-Rodrigo and Piqueras (2003) and Delaney-Rivera et al. (2009). The results show how the size of both punctures matches the largest ones visible on Fig. 3a, comparable with bears, large canids, or hyenas.

The punctures have been produced by both canines (left and right) of a carnivore with an intercanine width of 17.74 mm, which would correspond to a medium-sized carnivore, according to Murmann et al. (2006). If we take in account our forensic observations (Fig. 2) and the probable size orientation provided by neotaphonomic studies (Fig. 3a), we can propose that the Cova Negra Neanderthal represented by the CN42174b fragment reflects an attack by a large felid. This is something coherent in relation with the faunal spectrum present at Cova Negra Mousterian levels, where *Panthera pardus* has been identified (Villaverde et al. 1996). This interpretation is different to the one provided by Arsuaga et al. (2007), where they argued that the carnivore damage was generated postmortem by a fox-size carnivore. This new interpretation is related to our present taphonomic analysis of the fossil specimen.

Nevertheless, application of our forensic observations to the paleoanthropological record is not the only strategy available to verify past carnivore attacks on Neanderthals. Proof can also be obtained by paying attention to the paleopathologies displayed by Neanderthal skeletons.

Berger and Trinkaus (1995) studied traumatic lesions and posttraumatic degenerative changes in a large Neanderthal skeleton assemblage obtained from different archaeological sites. These authors recognized a high incidence of Neanderthal head and neck trauma (Berger and Trinkaus 1995: 845) and considered that anatomical distribution of traumatic lesions could provide an insight into Neanderthal behavioral patterns (Berger and Trinkaus 1995: 841); we would agree with this. They attempted to understand these lesions by comparing trauma among Neanderthals with lesion distributions from different recent human samples. The Neanderthal traumatic lesion pattern appears to be extremely similar to the one presented by North American professional rodeo athletes (Berger and Trinkaus 1995: 848). Berger and Trinkaus's main conclusion was that this general pattern was the result of frequent close encounters between Neanderthals and dangerous

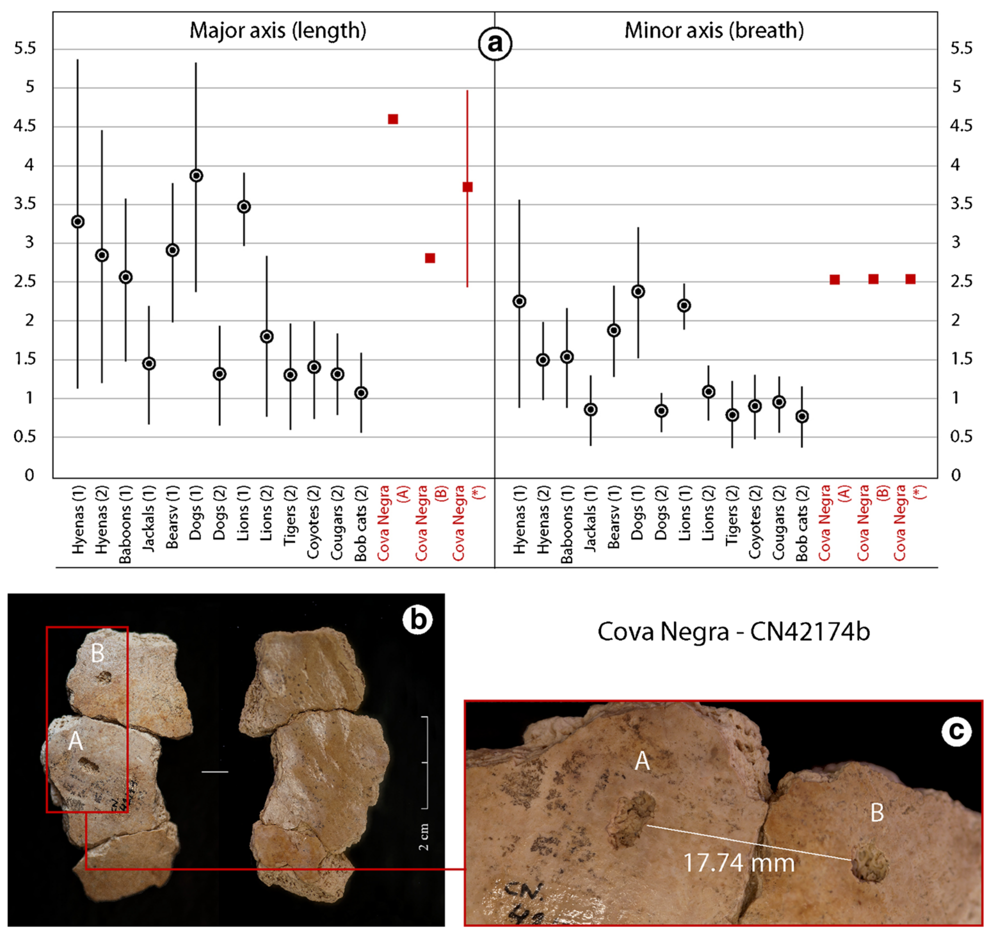

Fig. 3 **a** Cova Negra puncture sizes compared to the mean percentages of tooth pit sizes on diaphyses produced by different carnivores, according to Domínguez-Rodrigo and Piqueras (2003) (*1*) and Delaney-Rivera et al. (2009) (*2*); **b** Cova Negra right parietal CN42174b with punctures *A* and *B* highlighted and **c** detail of the punctures with the interpuncture distance measured

prey, due to their hunting strategy (defined by their available body-to-body technology) (Berger and Trinkaus 1995: 850).

The anatomical distribution pattern of traumatic lesions generated by carnivore attacks on modern humans is plotted in Fig. 4a, together with the one provided by Berger and Trinkaus (1995). A close match is evident between the Neanderthal distribution and attacked humans, providing an alternative explanation to the "rodeo rider" hypothesis and a plausible scenario that could explain Neanderthal trauma.

The similarity of the trauma pattern between Neanderthal and Early Anatomically Modern Humans (EAMH) has led to recent questioning of the rodeo rider analogy (Trinkaus 2012). New alternatives, such as interhuman violence, are now proposed to explain the persistence of a similar traumatic injury pattern in the Upper Paleolithic (Trinkaus 2012: 3693). Results of a foraging mobility can also be an explanation for this common pattern (Trinkaus 2012: 3692), as has already been proposed (Berger and Trinkaus 1995).

The injury pattern of humans attacked by carnivores has also been compared with the anatomical distribution of traumatic injuries in EAMH provided by Trinkaus (2012), and it also showed a close match (Fig. 4b).

In this sense, direct confrontation between Neanderthals and carnivores could represent an alternative and plausible explanation for the injury pattern found on Neanderthal anatomical remains. Dangerous encounters between Neanderthals and large carnivores would be reflected in their skeletons in the form of fractured bones or injuries derived from posttraumatic degenerative osteological changes, as happens with modern cases (e.g., arthritis; see Burdge et al. 1985).

Furthermore, we can propose direct confrontation as a form of interaction between hominins and carnivores that also affected EAMH during the Upper Paleolithic. This would give an idea of the long duration of conflict between hominins and carnivores during the Pleistocene, which continues even in the present time due to mutual pressures.

The scenario of hominins as carnivore preys appears to be much more common than it was previously thought. Predation among hominins is not just restricted to Neanderthals and EAMH as we have discussed; early ancestors were also attacked (e.g., Brain 1981; Bunn and Ezzo 1993; Boaz et al. 2004; Eppinger et al. 2006; Baquedano et al. 2012; Curnoe and Brink 2010). Therefore, confirming predation on hominins through past attacks, especially in early moments of our evolution, is an essential task to accomplish in order to analyze the development of hominin behavior as it is an influence for cooperation emergence (Hart and Sussman 2011) or technological development (Brain 1981).

The effort to confirm past carnivore attacks is important because it is possible to extract social aspects of this specific relationship. The study of social factors related with modern carnivore attacks on humans can give ideas about behavioral

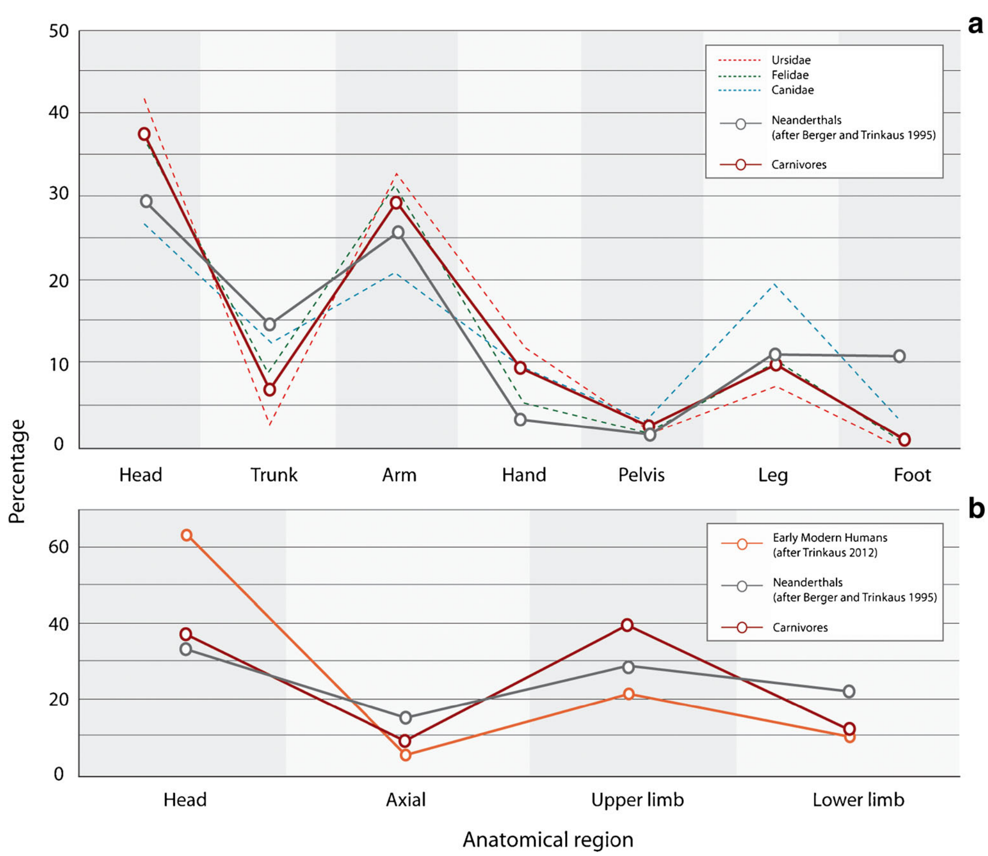

Fig. 4 Percentage distributions of traumatic lesions by anatomical region caused by carnivores compared to **a** Neanderthal lesions sample (Berger and Trinkaus 1995) and **b** Neanderthals and Early Modern Humans (Trinkaus 2012)

inferences derived from direct confrontation during the Pleistocene. An interesting issue is the fact that, in Tanzania, for example, risk factors are recognized that can result in a lion attack, such as poorly constructed huts, walking long distances to resources, sleeping outdoors at night, or sightings of bush pigs (Kushnira et al. 2010). In India, bear attacks are more related with territoriality, and villagers try to avoid attacks from bears by using a dog for protection and/or carrying weapons (Ambarli and Bilgin 2008). Another technique used in India to avoid bear attacks has been to travel in groups and avoid isolation (Agarwal et al. 2011), as nearly all attacks occurred when a person was alone collecting firewood in the forest (Dhar et al. 2008).

In North America, activities that involve carrying dead ungulates, such as hunting, may attract grizzly bears, and this could end in a dangerous encounter (Herrero and Fleck 1990). Concerning felines like cougars, jogging is an activity that may motivate a predatory attack (e.g., Neto et al. 2011). In the case of wolves, being accompanied by a dog may generate an aggressive behavior by wolves toward the dog (Linnell et al. 2002), although a common recommendation is to be accompanied by a dog to avoid carnivore attacks (see French 2001). In this sense, domesticated canids would provide security, although co-existing with dogs also has a high price due to the large number of domestic attacks recorded (Dhar et al. 2008).

Another significant factor related with social organization issues is the age and gender observed in a very high average of carnivore attacks in Asia. Rasool et al. (2010) report that the bear attack cases they studied (n=417) showed a predominance of middle-aged (96.8 %) male victims (80.33 %), which is attributed to the outdoor activities undertaken predominantly by men, rather than by women, in Indian society. This was also observed in Sumatra (Indonesia) with tiger attacks, where the typical victim is a middle-aged male working in his fields near the forest edge during the day (Nyhus and Tilson 2004). This pattern is also similar in Africa and may reflect a sexual division of labor or sex-differentiated ranging patterns among humans, as has been pointed out by Treves and Naughton-Treves (1999). A gender connection is also apparent in the confrontation between Maasai and lions, where spearing a male lion is part of a manhood ritual that provides immense prestige and a public display of bravery (Hazzah et al. 2009), as well as an inherent risk.

In summary, examples of current direct confrontation between humans and large carnivores can help explain past carnivore attacks on humans and contribute ideas about how to recover human behavior by analyzing this complex relationship (Treves and Naughton-Treves 1999).

Conclusion

The conflict between humans and large carnivores has been present and constant throughout human evolution, enduring even to modern times. This conflict made direct confrontation during the Pleistocene an inherent factor in the relationship between hominins and carnivores. We provide a forensic methodology that is useful in diagnosing carnivore-related damage on human bones and allows discernment of the type of carnivore responsible for lesions found on fossil hominins based on the anatomical patterning. Therefore, bone damage resulting from a current-day carnivore attack can be used in a positive manner to recover information about past carnivore attacks by comparing it with fossil hominin traumas.

In the present paper, we have applied our forensic observations to Neanderthal traumatic lesions provided by Berger and Trinkaus (1995) as a proof of concept and provide an alternative explanation to the paleopathologies present on the Neanderthal skeletons related to carnivore attacks. Although evidence of attacks on Neanderthals by carnivores has been gleaned by just studying paleoanthropological remains (Cova Negra is one example discussed here), we postulate that comparison of bone damage with current forensic records is also a positive strategy for recovering this information as an actualistic framework to generate new approaches. Furthermore, we have observed that EAMH lesions are also explainable in a context of attacks on humans by large carnivores. In this sense, we prove with our forensic methodology that not just Neanderthals were attacked by carnivores, also EAMH were. This scenario seems to have been common during the Pleistocene and continues today due to similar mutual pressures.

Therefore, predation on hominins appears to be a common scenario during the Pleistocene, and it has to be assumed as a constant influence in human evolution, and much more attention must be paid to this. In this sense, our methodology provides new insight in order to develop new perspectives concerning the role of predation in our evolution.

Understanding the dimensions of the conflict between hominins and carnivores and providing evidence of its consequences, such as carnivore attacks on fossil hominins, is an important issue due to its deep social and cultural implications. If we consider the current relationship between hominids and carnivores as a valid analogy (Treves and Naughton-Treves 1999; Hart and Sussman 2011), we will understand to the necessity of understanding the interaction between hominins and carnivores during the Pleistocene. Confirming past carnivore attacks is an important improvement on the knowledge of this issue, although more research is needed in future to calibrate its sociobiological implications in human evolution.

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