Toledo González, V. et al., 2021. Analysis of tooth mark patterns on bone remains caused by wolves (Canis lupus) and domestic dogs (Canis lupus familiaris) for taxonomic identification: A scoping review focused on their value as a forensic tool. Applied animal behaviour science, 240, p.105356.

Available at https://doi.org/10.1016/j.applanim.2021.105356

(Article begins on next page)

Analysis of tooth mark patterns on bone remains caused by wolves (*Canis lupus*) and domestic dogs (*Canis lupus familiaris*) for taxonomic identification: A scoping review focused on its value as a forensic tool

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ABSTRACT

The interaction between canids and humans is not free of conflicts. In Europe, wolves and dogs' attacks on domestic animals cause social and financial damages. The governments spend significant sums in compensation payments. Some of the allegations of wolf attacks on livestock may be false or difficult to prove. The insufficient expertise and unreliable methods used during the investigations often make it difficult to achieve a successful perpetrator identification, which leads to the stigmatization of this species and wrong paid compensations. Comparative studies of wolf and dog bite marks and tooth marks, to identify a potential aggressor agent, are very limited. In our study, 12,120 records were reviewed and only 16 of them fulfilled the search criteria set by the authors. Only one article carried out, exclusively, a comparison of wolf and dog bite mark patterns. These studies are commonly used in archaeological, paleontological and taphonomic contexts, but not in forensics. Despite the notable advances in bite mark analysis, most studies were carried out comparing bite marks from wolves and/or dogs and taxa belonging to other families. Currently, in forensic context, there is inconclusive evidence to certainly distinguish if the cause of death was created by wolves or domestic dogs using the forensic analysis of tooth/bite marks patterns from both canids (beyond any reasonable doubt). New and complementary forensic tools must be developed to differentiate between these two subspecies with a higher degree of certainty. Forensic veterinary odontology could play an important role in fulfilling this goal. The aim of the present work is to review and evaluate the studies on the identification of tooth marks on bone remains caused by two subspecies belonging to the same genus, wolves and domestic dogs. The variables, instrumentation, and development of future forensic investigations in this context are discussed. Based on the results obtained in this review, new standardized projects are needed to differentiate bites by wolves and dogs using forensic dental veterinary analysis.

KEY WORDS: bite marks, bite patterns, tooth marks, wolves, dogs, forensic veterinary.

1. INTRODUCTION

Taphonomy is the study of processes that affect a body from the time of death until the remains are found. These processes may be caused by natural, anthropogenic or cultural factors. Most taphonomic studies have been used for disciplines such as paleoecology, zooarchaeology, and archaeology. They are meant to interpret the preservation and accumulation of animal bones at an archaeological site, the effect of carnivores on bone remains, and to identify the factors associated with the damage caused to those bones (Andrews, 1995). Forensic taphonomy can be defined as the implementation of taphonomic models within a medical and legal context focusing on short-term processes occurring after death (Adlam and Simmons, 2007). Scavenging is a well-known taphonomic *post mortem* modification that can occur when a dead body is available to wild and domestic animals (Colard et al., 2015). Scavenging and taphonomic changes can distort body identification (Moraitis and Spiliopoulou, 2010) due to its destruction and dispersion (Colard et al., 2015). In forensic cases, scavenging is related to the animal's ability to scatter or destroy dead bodies, altering their skeletal remains, which may be evidence of the cause and manner of death. The scavenger can alter the bone surfaces in many ways depending on the typical behaviour of the species, the size (Delaney-Rivera et al., 2009), whether it is free or in captivity, the carcass longevity (Pobiner, 2008; Gidna et al., 2013), jaw characteristics, biting force (Christiansen and Wroe, 2007), osseous morphology, and environmental factors (Haynes, 1980). Bite analysis might help forensic experts to identify the taphonomic agent and to interpret its behaviour and scavenging patterns. Mammals have received special attention as taphonomic agents due to the similarity of their teeth and food habits within the same order. Therefore, there was a tendency to generalize the nature of their modifications within certain taxa (Binford, 1981). The taphonomic alterations caused by scavenger mammals to bones include both fractures and bite marks (Young et al., 2015). Various factors make it possible to study the action of carnivores. A common taphonomic technique is the direct study of tooth marks (Aramendi et al., 2017). Bonnichsen, cited by (Santoro et al., 2011) found that although the bite marks of carnivores vary, these leave predictable patterns on bones due to diverse factors such as jaw size, bite force, bone size and density, etc. Because of these factors, it has been argued that the study of tooth marks can be a useful tool for differentiating carnivores (Delaney-Rivera et al., 2009). Studies of bone damage by canids have been less frequent over the last five years (Young et al., 2015; Aramendi et al., 2017; Yravedra et al., 2017). However, most of these studies are geared towards determining the impact of those carnivores on the site formation process and the resulting bone damage. They do not set general scientific criteria that permit the identification of the carnivores by their bite marks (Pobiner, 2008). From an archaeological, zoological archaeological, conservationist, and forensic point of view, studies on bite marks have been conducted mainly on terrestrial carnivores. The comparative works focused on wolves (*Canis lupus*) (Haynes, 1980; Binford, 1981; D'Andrea and Gotthardt, 1984; Smith, 2005; Andres et al., 2012; Lescureux and Linnell, 2014; Iglesias et al., 2017) and other species and domestic dogs (*Canis lupus familiaris*) (D'Andrea and Gotthardt, 1984; Domínguez-Rodrigo and Piqueras, 2003; Delaney-Rivera et al., 2009; Lescureux and Linnell, 2014; Iglesias et al., 2017). Wolves preferably prey on wild animals (Mattioli et al., 2011), and domestic ungulates (Kaartinen et al., 2009), hence causing greater conflicts with humans and their economic interests in the case of livestock (Murray, 2006). Until 2016, a population of 17,000 wolves were present in continental Europe (Linnell and Cretois, 2018). Wolves are essentially considered a large and broadly distributed metapopulation with several distinct subpopulations (Boitani et al., 2018). Dogs are widely distributed in southern European countries, coexisting with wolves, which means that wolf predations can sometimes be confused with those caused by other carnivores (Cozza et al., 1996). Complicated working conditions in the field, insufficient expertise (Williams and Johnston, 2004), and unreliable methods used for the identification (Cozza et al., 1996) often make it difficult to successfully determine the attacker (wolves or dogs). The case-solving strategies are inefficient due to the increased compensation costs, which finally encourage some farm breeders to make false predation allegations. Consequently, efficient and accurate predator identification tools need to be developed (Caniglia et al., 2012). A scoping review is presented to determine and evaluate the studies analysing the identification of bite marks caused by wolves and domestics dogs on bone remains. This takes into account the current problem caused by wolves and dogs in Spain, considering that the majority of forensic studies related to scavenger modifications of bone remains focus on the general characterization of bone modification produced by a biological family of scavengers. The variables, instrumentation, and possible future forensic investigations are discussed. Based on the results obtained in this review, new standardized projects will be proposed to differentiate the bites caused by Iberian wolves (*Canis lupus signatus*) and domestic dogs, using a forensic dental veterinary analysis.

2. MATERIALS AND METHODS

A scoping review was performed of the literature on individual and comparative forensic studies of bite patterns and tooth marks caused by wolves and domestics dogs between 1980 and June 2019. The search strategy and inclusion of the articles studied was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA®) statement published in 2009 (Moher et al., 2010). Figure 1 shows the PRISMA flowchart which describes the search methodology used for selecting the articles examined in this revision. An electronic search was made on the SCIENCE DIRECT, MEDLINE/PubMed, SCOPUS, RESEARCH GATE and SciELO databases from February to June 2019 using the search terms ("canids" OR "dogs" OR "wolves") AND ("bite marks" OR "bitemarks" OR "tooth marks" OR "scavenging") AND ("bones" OR "taphonomy") and combinations of these terms. Further search methods included manual searching in selected journals such as the Journal of Forensic Science, Forensic Science International, the Journal of Forensic and Legal Medicine, the Journal of Forensic and Legal Medicine and the Journal of Taphonomy. This was done to identify studies that may not have been located through electronic database searching. Detailed search strategies were developed for each Journal. Only original full papers in English, Portuguese and Spanish were included. The publications were excluded if they did not include the comparative analysis of morphological and/or morphometric bite marks by wolves and/or dogs, or studies citing previous papers, once the full original study was available. Two researchers carried out the search in a parallel and independent way to avoid any systematic error. The articles selected were evaluated by adapting the critical evaluation guide of the Journal of the American Medical Association (JAMA) (Hayward et al., 1995). Once the subject of each selected article was established, the researchers analysed their main titles and the summaries. Finally, the researchers reviewed the articles, and if any discrepancies existed, a third researcher assisted them in order to reach a final decision. The following categories were considered in the study: author's nationality, countries in the sample, samples used, and measurement instruments used for the bite mark morphology/morphometric analysis.

3. RESULTS

The database search resulted in 12,120 articles. After excluding duplicate records, as well as conferences, books and other communication media, which did not meet the inclusion criteria, 16 articles remained (Figure 1). A complementary manual search did not yield additional results. Most of the papers (> 91 %) dealing with wolf and/or dog bite mark analysis (morphology and/or morphometric) appeared between 2012 and 2017, except for publications from 2003 (Domínguez-Rodrigo and Piqueras, 2003) and 2006 (Murmann et al., 2006). In America and Europe, the United States and Spain, respectively, have a strong participation (56.2% of the articles). No activity in the rest of the America, Asian or African continents was observed. Wild and captive wolves, felids, and hyenas are the main species included in the bite mark studies. Only a few of these articles included wild or domestic dogs (Table 1). Six articles compared wolves and others carnivores/omnivores (Haynes, 1980; 1983; Dominguez-Rodrigo et al., 2012; Burke, 2013; Aramendi et al., 2017; Yravedra et al., 2017); four articles compared only wolves (Yravedra et al., 2011; Fosse et al., 2012; Parkinson et al., 2014; Sala et al., 2014), and three articles compared dogs and other carnivores/omnivores (Domínguez-Rodrigo and Piqueras, 2003; Delaney-Rivera et al., 2009; Young et al., 2015). Two articles compared wolves, dogs and others (Murmann et al., 2006; Andres et al., 2012) and only one article performed, exclusively, a comparison of wolf and dog bite mark patterns (Yravedra et al.,

2014) .

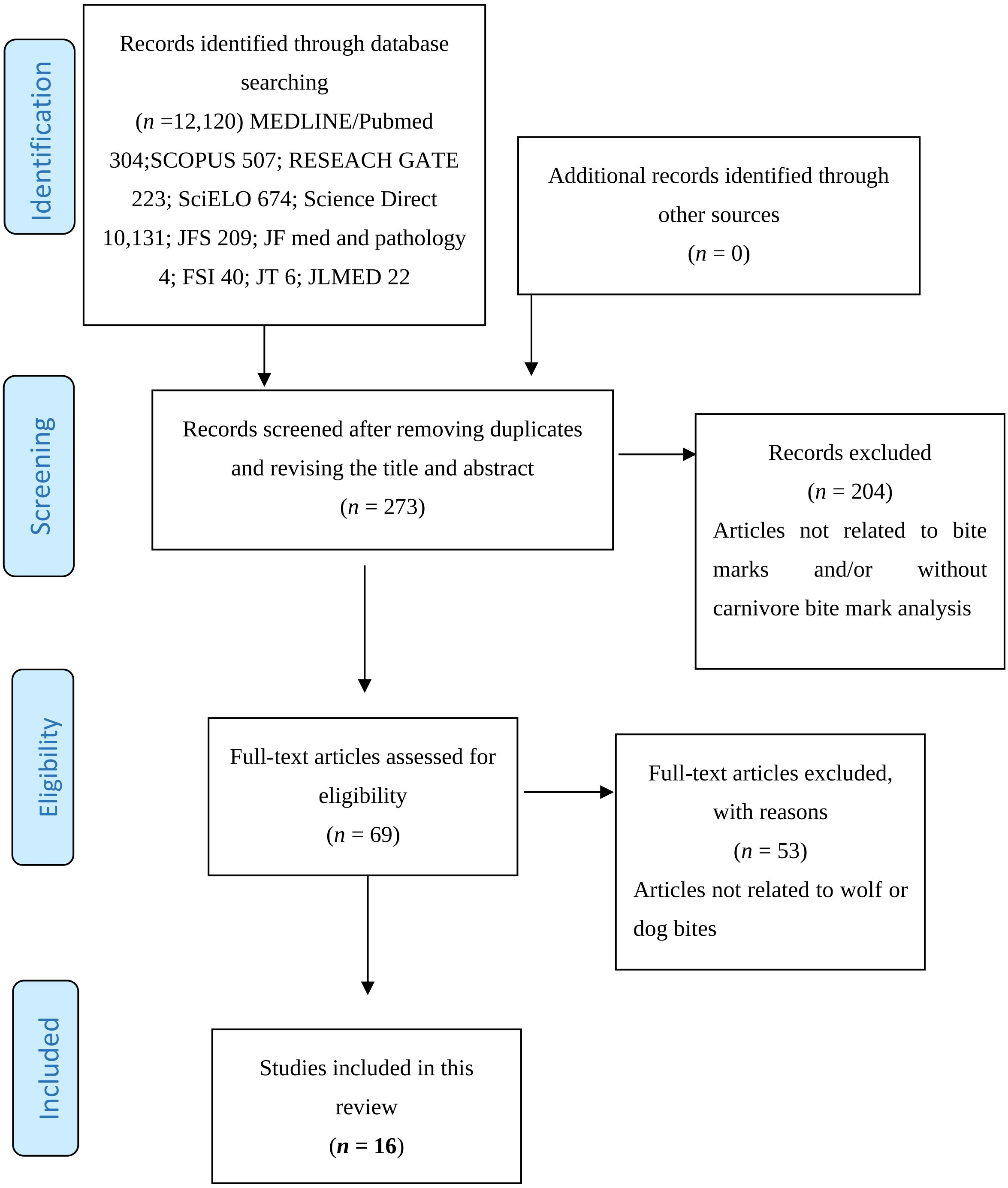

Figure 1. PRISMA flowchart describing the search strategy and inclusion of the articles studied in this revision.

Table 1. Summary of the included authors. The following items are shown: authors and year, author`s country, studied samples and scavenger, sample origin, analysed variables, methodology, and principal outcomes.

(a) Author (s), year	(b) Author´s country	(c) Scavenged samples	(d) Scavenger Species Common names	(e) Sample origin	(f) Variables analysed	(g) Methodology	(h) Principal outcomes
Haynes (1980)	USA	Bones of large animals (antlers carcasses)	Wolves, bears. large cats	Collection from many sites	Bone modifications	Direct analysis of marks	Furrow tooth mark dimensions: 2-4 cm length and about 4 mm wide created by adult wolf teeth. Fractures on shafts and intensive gnawed on the ends of large bones. Wolf gnawing also produces short nicks, single grooves, and other marks according to the type of bones. On scapula, 1-2 cm diameter holes can be found, sometimes surrounded by concentric ring cracks
Haynes (1983)	USA	Fresh limb bones of domestic cattle	Wolves, hyena, bear, lion, tiger, and jaguar	Not mentioned	Sequences and type of bone damage, time lengths	Direct analysis of marks (unspecified)	Furrow tooth marks at the ends of large bones were found. Compact tissue removed in patches (1 mm diameter) exposing the trabecular bone. Presence of scratches near the ends of the diaphysis
Domínguez-Rodrigo and Piqueras (2003)	Spain	Bovid or equids	Dogs, lions, jackals, bears, hyenids, and baboons	Dogs from previous works	Conspicuous marks on molds. Pits and scores (length and breadth)	Binocular lenses and an electronic caliper	The size of both pits and scores tooth marks are bigger on cancellous bone tissue than on the dense cortical surfaces In domestic dogs, the Pit length of tooth marks on cancellous bone marks was 4–6 mm; Pit breadth tooth marks above 4 mm. On diaphysis (thick cortical bone): above 2 mm long and 1.5 mm broad can be attributed to dogs but they are only clearly established when the size is larger than 4 mm in length and 2 mm in breadth. A general phenomenon of convergence makes it almost impossible to isolate a certain carnivore species based solely on the tooth pit dimensions on cortical bone surfaces. Correlation is not regular in scores tooth marks
Murmann et al. (2006)	USA	Bite marks on wax from Grey Wolf, domestic dog, Gray Wolf, domestic cat, bobcat, lynx, mountain lion, Gray fox, red fox, coyote, , wolverine, black bear and grizzly bear	Not applicable	Museum collection (Illinois)	Maximum canine width (MCW), canine cusp tip (Tip), and mesial bone height (MBH)	Dial caliper	Dog family measurement ranges (cm): Dogs: (n:35) Max MCW- Max. Tip- Max MBH - Mand Tip - Mand MBH 2.1-5 2.0-4.8 1.3-3.3 1.8-4.9 0.6-1.7 G. Wolf: (n:53) Max MCW - Max. Tip- Max MBH - Mand Tip - Mand MBH 4.1-5.3 3.7-5.1 2.3-3.0 3.6-4.5 1.0-1.0

Delaney-Rivera et al. (2009)	USA	Defleshed goat and cow	Dogs, American alligator, Virginia opossum, red fox, human, coyote, striped skunk, American coati, raccoon, felines, and hyena	California	Pits, punctures, scores, and furrows	Digital photography	Great overlapping in the tooth pit and scores sizes among the taxa that vary substantially in body mass. Measurement in domestic dogs were: Tooth pits (mm) major axis minor axis Epiphysis - - Metaphysis 1.752 1.009 Diaphysis 1.308 0.832 Tooth scores (mm) Epiphysis - - Metaphysis 5.815 1.146 Diaphysis 4.434 0.604
Yravedra et al. (2011)	Spain	Long bones of young and adult horse	Wolves	A Coruña	Percentage, number of tooth marks and survival rate for every anatomical part	Hand lens (10-20X) and digital caliper and Kruskall Wallis and Mann Whitney's statistical tests	The intensity of bone modification depends on the number of consumption events (access to carcass), hunting and scavenging strategies, and the consumed carcasses size. No teeth mark dimensions were stated. Just descriptive
Andrés et al. (2012)	Spain	Long bones of equids and bovids	Dogs, wolves, baboons, spotted hyenas, lions, foxes, wolves, humans, and lions	Samples of previous works	Conspicuous and inconspicuous marks: Dimension of pits and scores	Hand lenses (15-20x) and electronic caliper	Large and smaller carnivores can be potentially differentiated. Exists strong overlapping between large carnivores (dogs and wolves) bite marks. Better differentiation may be obtained by comparing the tooth marks on dense cortical shafts rather than on spongy ends Pit measurements (mm) Wolf shaft breadth 1.8 Wolf shaft length 2.49 Wolf end breadth 2.7 Wolf end length 3.61 Dog shaft breadth 1.36 Dog shaft length 1.77 Dog end breadth 1.9 Dog end length 2.4 Score measurements (mm) Wolf shaft breadth 1.68 Wolf shaft length 8.62 Wolf end breadth 2.92 Wolf end length 10.76 Dog shaft breadth 0.66 Dog shaft length 5.06 Dog end breadth 0.81 Dog end length 5.95
Fosse et al. (2012)	France, Poland, Spain, USA	Deer and bison adult carcasses	Wolves	Samples of previous works	Intensity of teeth modification on carcasses, number and type of bone remains	Direct observation on bones	No teeth mark dimensions were described. Repeated consumption can cause a big dislocation and dispersion of the bones. Damage on bison`s long bones varies, both in terms of tooth mark diversity and intensity. On deer, the bones heads and axial elements suffer a bigger damage (especially punctures) than appendicular bones (mainly destroyed by scores and pits)

Domínguez-Rodrigo et al. (2012)	Spain, United States	Equid carcasses	Wolves, spotted hyenas, and lions	Wolves: samples of previous works	Presence/ absence of tooth marks	Multivariate analysis	No tooth mark dimensions were described Is possible to differentiate this taxon analysing combined variables and using homogeneous samples
Burke (2013)	USA	Hind limbs of cattle, hind limbs of sheep	Wolves, coyotes, mountain lions, bobcats, grizzly bears, and black bears	Nevada, Reno	Tooth marks: Punctures, pits and scores	Video set to capture sequence of behaviours	No tooth mark dimensions were described The most prominent tooth marks on the elements fed on by wolves included scoring and punctures, with furrowing and pitting secondary concentrate on proximal epiphyseal end of the femur and tibia The measurement of tooth marks sizes and shapes may be of lesser importance in distinguishing scavenging carnivores than a more holistic ability to demonstrate the mechanics of different scavenger taxa's jaw mechanics and feeding behaviours
Parkinson et al. (2014)	United States	Deer carcass and bison limbs	Captive wolves	New York and local farms. (Road killed animals)	Distribution, frequencies of tooth marks. Survivors and gross bone damage patterns	GIS image-analysis method	No tooth mark dimensions were described The degree of tooth patterns are different between the small and large groups rather than kind of tooth mark The distribution of tooth pits on long bones is not random Abundance of tooth marking on ends Negative but non-significant relationship between bone density and tooth mark frequency
Yravedra et al. (2014)	Spain	Equid long bones, scapulae, innominate, calcaneus, and talus	African wild dogs and captive wolves	Cabárceno Natural Park (Cantabria)	Conspicuous and inconspicuous marks Dimensions and others	Hand lenses (10–20) and electronic caliper directly on the marks	African wild dogs and captive wolves clearly showed preferences for the upper appendicular elements. The frequencies regarding the marks per bone were often low. There were pits and scores tooth marks, distributed on all appendicular elements, both on diaphysial (Diaph) and epiphyseal (Eph) sections: Measurements (mm): a) **Pits**: Diaph. Length = 1.1 mm; Diaph. Width = 0.76 mm. Eph. length = 2.66 mm; Eph. width = 2.02 mm. b) **Scores**: Diaph. Length = 5.43 mm; Diaph. width = 0.42 mm; Eph. length = 5.1 mm; Eph. width = 0.7 mm Tooth marks sized caused by African dogs tend to be narrower and smaller than caused by wolves

Sala et al. (2014)	Spain, USA	Deer carcasses (fresh or frozen); Carcass parts of horse, cattle, domesticated camelids and pig	Wild and captive wolves	Spain, USA and Canada	Length and breadth of tooth marks: on spongy or cancellous, thinning cortical and cortical bone portions	Nikon SMZ800 (stereoscopic zoom microscope). Digital caliper Univariate analysis, Kruskall Wallis test and Mann Whitney statistical test	The wolves in captivity caused further bone changes than the wild ones. Pits and scores were the main types of tooth marks caused. Punctures length/breath (mm) dimensions on cancellous, thin cortical and cortical were 4.35 / 3.34; 3.9 / 3.12 and 3.56/ 2.73, respectively Pits length/breath (mm) on cancellous, thin cortical and cortical were 2.81 / 2.31; 2.7 / 2.08 and 2.11/ 2.35, respectively Scores breath on cancellous, thin cortical and cortical were 2.35; 1.07 and 1.29 mm, respectively
Young et al. (2015)	UK	Adult deer carcasses	<u>Domestic dogs,</u> wild red fox, captive Eurasian badger	UK	Pits and scores (Length and breadth)	Hand lens (2-6x) and digital caliper; Pearson's and Spear- man's coefficient correlations Separate Kruskall–Wallis test	<u>Small-sized dogs</u>: Scores were the most frequently tooth marks found on bones The mean length of pits was 3.25 mm, and the mean breadth was 1.88 mm. For scores, the mean length was 9.75 mm and the mean breadth was 1.91 mm. <u>Staffordshire Bull Terriers</u>: Pits had a mean length of 2.95 mm and a mean breadth of 2.20 mm. Scores had a mean length of 8.1 mm and a mean breadth of 1.50 mm The pit lengths and pit breadths found on the deer bones were significantly different to those on the bones scavenged among them
Aramendi et al. (2017)	Spain and South Africa	Adult horse long bones	<u>Wolves,</u> hyenas, jaguars, lions , and crocodiles	Wolf samples from Spain	Pits	Micro-Photogrammetric (3D) and Geometric morphometric analysis	High overlapping among carnivores bite marks No tooth mark dimensions were described
Yravedra et al. (2017)	Spain	Horses For foxes: sheep	<u>Wild wolves</u>, lions, hyenas, jaguars, and foxes	Samples of previous works	Teeth marks: scores identified on shafts	Photogrammetric techniques; Geometric Morphometric and multivariate statistics	No tooth mark dimensions were described Although a big overlapping exists, using particular statistical test it is possible to distinguish each carnivore group based on the score dimension. This is true except for the wolves and jaguars

The comparative analysis of tooth marks shown on Table 1 refers mainly to the following variables: presence/absence, frequencies, distribution, and percentage of conspicuous and inconspicuous tooth marks on bone portions, intensity of these tooth modifications on carcasses, bone survival, and morphology / morphometric (length and breadth). Only in eight of the 16 articles did the authors give information about tooth mark dimension (Haynes, 1980; 1983; Domínguez-Rodrigo and Piqueras, 2003; Murmann et al., 2006; Delaney-Rivera et al., 2009; Andres et al., 2012; Yravedra et al., 2014; Young et al., 2015). Fifteen worked on bones (mainly on long bones of bovid, horses, bison, and deer), and one on inert substrate (dental wax) (Murmann et al., 2006). Yravedra and Domínguez-Rodrigo (Spain) stand out for their participation in 50.5 and 42.9 % of the papers selected, respectively. The use of direct observation of the tooth marks and photographic images are the methods generally applied in morphological analysis, while univariate and multivariate statistical methods are used in comparative morphometric analysis.

There are several definitions, classifications, and descriptions about tooth marks between the 1980s (Haglund et al., 1988) and the past decade (Andres et al., 2012). In any case, four types of marks were studied more frequently in morphometric analysis. Briefly, punctures and tooth pits are oval, circular, and polygonal marks made by the application of direct pressure on bone surfaces (Pobiner, 2008), among others. Pits are generally more superficial marks and do not penetrate the deeper cortical bone layers (Gidna et al., 2013; Colard et al., 2015). Scorings are linear marks caused by the carry-over effect of the teeth on the bone surface. They have a length three times greater than their breadth (Delaney-Rivera et al., 2009). Scores do not penetrate compact bones and have variable length and orientation (Pobiner, 2008). Furrowing are variably orientated, relatively deep, linear and elongated marks (Haynes, 1983) that can penetrate compact bones (Pobiner, 2008) (Figure 2).

Our results show that there is a clear tendency to use tooth mark analysis in order to differentiate American and European wolves or dogs from animals belonging to different families. Only Andrés et al. (2012) and Yravedra et al. (2014) performed minimal studies for comparing animals belonging to the same genus such as wolves and domestic dogs. In both studies, the dimensions of the analysed tooth marks (pits and scores) caused by dogs were narrower and smaller than those caused by wolves (Table 1, column h). On the one side, Andrés et al. (2012) considered two groups of carnivores using databases from previous studies. Iberian wolves (*Canis lupus*) versus domestic dog breeds (German Shepherd), comparing both small (< 40 kg) and large (> 40 kg) sizes. Interestingly, the German Shepherd breed was called a “non-modified breed”, meaning that they retain characteristics most similar to wolves (Ameen et al., 2017). Predictably, diverse overlapping degrees of tooth marks were found. They concluded that only large and smaller carnivores can be potentially differentiated to a higher degree of discrimination when using tooth marks on cortical dense shafts (cortical bone on long bones) as opposed to spongy ends (cancellous bone). More specifically, this refers to using pit width and not length dimensions. On the other hand, Yravedra et al. (2014) concluded that the African wild dog’s (*Lycaon pictus*) teeth marks tend to be smaller and narrower than those from wolves. Pits on diaphysis (shaft) were smaller compared to those produced by wolves (Table 1, column h). Moreover, the epiphyses (cancellous bone) did not show a variability range different from that documented for wolves. They considered the lesser bone modification degree and tooth mark size range and reported that the African wild dog’s behaviour seemed to focus more on meat rather than bone consumption during the carcass processing. This conclusion indirectly supports previous findings (Yravedra et al., 2011), which pointed out that the muscle mass present could alter the degree of bone modification. Consequently, the carcasses covered with significant muscle mass will undergo a lower degree of bone modification when given to animals that tend to eat meat rather than bone. It is necessary to indicate that Yravedra et al. (2014) analysed a larger number of variables than Andrés et al. (2012), including mark number, percentages, and frequency, anatomical distribution of the tooth mark types, and bone fracture type and pattern (Table 1, column f). Despite the results achieved by both research groups and the other selected authors, we will discuss several of the variables considered in the methodology of those studies.

4. DISCUSSION

Some authors indicate that the studies related to bone damage by canids are less frequent than others including several animal taxa. However, when searching for actual studies on wolf and dog bite marks, the findings are not too encouraging. The results obtained are ambiguous, and the variables and methodologies involved in each study are different and interesting to discuss in order to understand their relationship with the mentioned results.

Firstly, Andrés et al. (2012) classified the German Shepherd breed used in their study as a large animal. Differentiating tooth marks between these two subspecies remains a major challenge because they are very similar, and therefore more difficult to tell apart. However, according to the established characteristics provided by the Federation Cynologique Internationale (AISBL) (Federation Cynologique Internationale, 2010) for the German Shepherd breed, these animals should be classified as small-sized dogs (< 40 kg) and not as large ones. Under these conditions, some significant differences and smaller overlapping should be noted between both subspecies. Detailed information about the dog's weight used in the study is not clear and this is unfortunate. Therefore, it is impossible to state whether these variables (weight or tooth mark difference sizes) caused any overlapping or whether there are other reasons for these results. Obviously, carnivore size alone could be just one of the variables causing this unclear overlapping (Andres et al., 2012). Yravedra et al. (2014) conclude using the word "tend to be" (Table 1, column h), which could be counterproductive from a forensic perspective. This is because it lacks the certainty required for prosecuting a suspect and may generate varying interpretations and reasonable doubts.

Overlapping is a common trait in many of the studies selected in this work (Delaney-Rivera et al., 2009; Andres et al., 2012; Aramendi et al., 2017; Yravedra et al., 2017) (Table 1, column h). However, apart from the weight, several other factors can be associated with overlapping or its severity, as was already mentioned by Andrés, et al. (2012). Some of these factors may be specific to the sample, animals or environment, and many of them were not considered by the authors selected or were only partially considered. One of them is the exposition time of the bone to the scavenging animal. Burque (2013), using new technologies such as video recorders (Table1, column g), provided a more complete, secure and reliable description of this relationship (tooth mark versus behaviour) in wolves. He noted an extensive presence of pitting, scoring, and extreme furrowing (Table 1, column h). The results were linked to "*boredom*" in the dens and dog yards, or to non-nutritional (recreational) gnawing (Campmas and Beauval cited by (Binford, 1981). The animals could spend more time chewing the bones "*at home*" (but not in killing sites). These results can be associated to the exposition time to the bone, also cited by other authors (Haynes, 1983; Fosse et al., 2012). Young et al. (2015) focused on identifying bite marks and ranges of bite marks caused by two different groups of domestic dogs working on adult deer carcasses: small and large. The mean pit length caused by small dogs was larger than the marks created by large dogs (Table 1, column h). Smaller dogs would have less bite force and smaller tooth morphology, which would have affected their scavenging behaviour. They would have used their dentition, spending more scavenging time to cause marks larger than those of large dogs do. On the contrary, the Staffordshire dog breeds spent less time causing major destruction, resulting in bite marks with smaller dimensions, higher bone survival rates, and therefore, less overlapping of tooth marks, which is a characteristic also analysed by other authors (Haynes, 1983; Domínguez-Rodrigo and Piqueras, 2003; Delaney-Rivera et al., 2009). This could explain, at least in part, the results obtained by Andres et al. (2012), when they concluded that a differentiation between large and smaller carnivores can be possible by using only the pit breadth dimension. Regrettably, we have no information about exposition time. Yravedra et al. (2014) talked about the behaviour and consumption strategies (wolf hunting or scavenging), while Campmas and Beauval, cited by Binford (1981), mentioned non-nutritional (recreational) gnawing. In fact, in 1983, Haynes was aware of this “recreational gnawing” and called it “home chewing”. In nature, wolves must hunt on their own to obtain food. It may be easier when there is no natural competition, that is, within the same wolf pack or with other animals. Fosse et al. (2012), working with wolves, noted that the results were affected by the time span for carcass consumption, also found in Domínguez-Rodrigo et al. (2012), and the number of wolves consuming (e.g., effects of inter-carnivore competition), also mentioned by Delaney-Rivera et al.(2009) and earlier by Haynes (1983). An intensified competition for food could mean less time to eat at the killing site. Yravedra et al. (2014) indicated that when consumption is very intense (e.g., several contacts between the wolves and the same bones), there was also a reported increase in the number of tooth marks per bone, the frequencies of tooth marks, and the dimensions of the portions processed. This may also mean a longer exposition time. In contrast, recreational gnawing needs a quiet space and longer time to occur. In this case, we would expect a larger degree of overlapping. Here we would face three different kind of behaviours: 1) right after hunting (primary consumption, which is the most important in wild wolves), 2) scavenging (even days after the primary consumption) and, 3) recreational activity. To get a better interpretation of results, we must take all these conditions into consideration in future studies. Sample size is another factor to be considered when looking at the degree of destruction and overlapping. Sala et al. (2014) took into account some limitations in their study, such as different wolf size and the taxa of the ungulate prey. Therefore, it was not evident if the living condition of the wild wolves and the size or hardness of the carcasses would be determining factors for these results. Large animals biting on small samples will cause a large amount of damage. On the contrary, small animals biting large samples will cause less damage, unless the animals spend more time on the act of biting. This could allow for diverse degrees of overlapping, especially with tooth marks on spongy bone zones. Obviously, small animals have lesser biting-force, so they might spend more time generating similar tooth marks. On hard bone zones (cortical bone), smaller animals could spend more time to reach the same effect, but why would they do so? For feeding (bone marrow) or during recreational activity? However, compact bone zones seem to be a good point for comparing tooth marks, because they are not as damaged as the spongy zones and the marks are better preserved. Again, we must thus considerer many factors for a logical interpretation of the results. Sample size was the probable cause of the results obtained by Delaney-Rivera et al. (2009) (e.g., considerable overlapping). They worked with small carcasses of defleshed goat limbs and, additionally, the taxa varied widely in terms of body mass (small, large carnivores, and omnivores). This fact was also discussed by Domínguez-Rodrigo et al. (2012), who mentioned that the small samples used in the statistical analysis could also be another important factor. As early as the 1980s, Haynes indicated that modern carnivores did not always produce recognizable tooth marks on bones. He also mentioned a broad range of variables that can influence bone modification patterns, making them resemble natural processes. Examples include weathering or animal gnawing, the time the bones have aged, the species and number of carnivores causing the gnawing, the prey species, seasonal variation, availability, vulnerability, and others. Some of these variables are not considered in recent studies. When we talk about the bone zones most susceptible to destruction, we are implicitly talking about a concept already considered by Haynes (1983), namely density. His work included more variables related to bone modifications caused by wolves and a larger number of carnivores than two years before (Haynes, 1980). He described differences between tooth marks registered on distinct bone portions of varying density and composition as a factor of overlapping. Obviously, some natural conditions are included in the density concept; for example, the humidity of the sample (dry and fresh-deposited bone remains), which was also taken into account by Domínguez-Rodrigo and Piqueras (2003) and Delaney-Rivera et al. (2009). Spongy bones at the ends of long bones have lower density than at the shaft (dense cortical bone). However, several works showed a greater degree of modification on cancellous bones than on the shaft of long bones (Domínguez-Rodrigo and Piqueras, 2003; Burke, 2013; Parkinson et al., 2014; Sala et al., 2014). Finally, it appears that the degree of modification depends on the exposition time, among other possible factors. Jointly, bone density and exposition play an important role in the resistance to modifications. That is why, in some cases, some teeth marks on dense cortical shafts were important when differentiating animals (Andres et al., 2012). This is due to the more limited destruction and greater conservation of the teeth marks. Moreover, a lesser degree of overlapping was found on dense cortical shafts (Andres et al., 2012). Although other authors found teeth marks, they concluded that there is a negative yet non-significant relationship between bone density and tooth mark frequency (Parkinson et al., 2014). Other factors not considered in that study could likely be responsible for their conclusions. These factors could also affect the results in Sala et al. (2014) study based on captive wolves. Twenty years later from the Haynes's publication, Domínguez-Rodrigo and Piqueras (2003) categorized conspicuous marks by bone regions according to their density. They evaluated animals that are interesting to us, including the domestic dog (German Shepherd breed). Their results were similar to those from previous studies: 1) larger pit and score sizes on cancellous bones tissues than on dense cortical bone; 2) a high overlapping degree for the pit dimensions; 3) it was possible to differentiate two separate groups of animals although the dogs` teeth marks once again showed overlapping with the teeth marks caused by other animals. It was found that the teeth marks alone (pits) were too ambiguous to be used to differentiate among specific taxa. This was true, unless new variables were incorporated in the analysis (e.g., large sample, furrowing, etc.). Consequently, a global sample and teeth mark ranges of variation should be considered in future studies. Finally, they noted that a differentiation could only be possible when comparing bone damage (pit size) created by small- versus large-size carnivores. Although they included new variables (conspicuous variables), the results were similar to those in the other works selected. They explicitly mentioned that a global sample and the ranges of variation in teeth marks should be considered in futures studies. In this case, they performed an indirect analysis using molds from teeth pits and score sizes registered on long bones from equid and bovid carcasses and not a direct analysis of the bones.

4.1 Characteristics and origin of the samples.

As mentioned above, several comparative teeth marks studies were conducted using diverse types of non-standardized bones (samples) (Table 1, column e). The bones were long, flat, articulated or not, defleshed or not, fresh or not, from adult or young animals, belonging to taxa of ancient and contemporary animals. Some of these samples came from museum collections (even from faraway countries) and just a few of them were prepared especially for teeth mark studies (Table 1, column e). In fact, several of the teeth marks analysed were caused by wolves of different species and origin (American and European). Furthermore, it is important to mention that some authors (Domínguez-Rodrigo and Piqueras, 2003; Andres et al., 2012; Dominguez-Rodrigo et al., 2012; Fosse et al., 2012; Aramendi et al., 2017; Yravedra et al., 2017) elaborated their studies on the basis of previous experimental works. This may imply that there is a continued lack of detailed and complete information about the specific and previous characteristics of the samples and/or the animal taxa studied. The same happened with possible taphonomic changes due to the environmental condition during the preservation, conservation, and manipulation of the samples. In selected articles, these characteristics were not discussed as a possible source of variation of the outcomes. In 1980, Haynes noted that many of his samples, from a museum collection, did not have data about their provenance. In this case, the author was unaware of the influence of external factors that might throw off his findings. He had some ideas regarding the origin of the samples, indicating that most of the Alaska samples were thought to be derived from sediments in Wisconsin. More standardized samples are required in future studies for a more exact understanding and interpretation of the results. Those samples should include all kind of bones, not just long bones like in most of the selected studies, especially for forensic analyses. Authors that are more recent mention the origin of the samples only at a general level. In a forensic context, a better interpretation of the results is based on comparisons made between standardized samples, evaluating the effect of qualitative and quantitative factors on the outcomes. Therefore, the results showed here should be taken with caution in forensic investigations.

4.2 Employed methodology

Since the 1980s, there has been a notable contribution to, as well as technological advances in, morphological and morphometric teeth mark analysis. These include the direct analysis of marks for the description of teeth marks, macro and microphotography, and modern anatomic techniques (e.g., geometric morphometric) using measurable and objective indicators. Obviously, these advances have greatly enhanced the development of a new statistics tool for tooth mark analysis, including simple average comparisons, univariate statistical analysis and multivariate statistical analysis (Table 1, column g). In fact, Domínguez-Rodrigo et al. (2012) pointed to the need to integrate new variables in multivariate analysis since they increased the differentiation between animal taxa, but only when working with homogenous samples. It is important to remember that a wide range of factors can affect the samples and therefore the results as well. Multivariate analysis can analyse quantitative and qualitative variables at the same time, making it possible to identify the main variables for differentiation. This is important, particularly if we try to differentiate tooth marks caused by two animals belonging to the same genus, such as wolves and domestic dogs. Therefore, standardized tooth mark patterns of wolves and dogs are required so that specific modern analyses can be applied.

4.3 Analysed variables

As indicated above (Table 1, column f), the main variables analysed were punctures, pits, scores, and furrowing. They were gathered thorough diverse techniques that are also mentioned above. The enormous heterogeneity within and among the samples produced results that were somewhat ambiguous to the naked eye. In other words, it is difficult to determine which variables are the best to differentiate between wolves and domestic dogs using teeth mark analysis.

4.4 Outcomes (Table 1, column h)

There is a clear understanding that morphologic and morphometric studies are complementary and required. More than 50 % of the articles selected do not describe teeth mark dimensions (Yravedra et al., 2011; Dominguez-Rodrigo et al., 2012; Fosse et al., 2012; Burke, 2013; Parkinson et al., 2014; Aramendi et al., 2017; Yravedra et al., 2017). The dimensions described include the width and length of the teeth marks but not the distances between them. We have discussed how sample characteristics can influence results. A deeper bite means that the tooth mark will be wider, especially in spongy zones (low density). On cortical bones, a deeper bite is more unlikely to occur, and the size will be smaller for the same teeth. Knowing the distances or distances intervals could possibly be more effective in producing more highly standardized data sets as previously mentioned by Murmann et al. (2006), especially with tooth mark patterns created on the low-density zones of bones. The use of these intervals could help to exclude the presence of one of the suspects, using the non-overlapping zones (the interval extremes) which would be useful for differentiation purposes as mentioned in other publications (Toledo González et al., 2020). Parkinson et al. (2014) did not provide information about tooth mark dimensions but they noted that the differences between the small and large wolf groups are simply differences of degree rather than a way to determine the kind of tooth marks. The degree of damage can be influenced by behaviour and consumption strategies or non-nutritional (recreational) gnawing, as stated above. Again, the rest of the findings could be conditioned by other factors not included in these studies. Obviously, regardless of the age of the samples (ancient or current), the analyses could never consider all of the factors described here. The results presented by Parkinson et al. (2014) represent an advance in the understanding of the human-animal relationship in the past. However, in a forensic context, it has very low reliability in present-day litigation, and it is easy to refute if complementary evidence or analyses are not also conducted.

It is very important to emphasize some important concepts in a forensic context. Burke (2013) clearly expressed that the tooth mark sizes and shapes alone may be much less relevant for distinguishing between the scavenging carnivores. Nonetheless, they may be able to separate the different jaw mechanics and feeding behaviour of the scavenger taxa. In the articles reviewed, bite/tooth mark studies (in a morphological or morphometric context) appeared as one of the most frequently used tools in disciplines like archaeology, palaeoanthropology and taphonomy. Certainly, the general objective was to distinguish several animal taxa as taphonomic agents present in the past. This was done by means of tooth bite mark analysis on bone remains. The studies tried to understand the relationship between coexisting animals (*e.g.*, competitiveness), and to interpret the archaeological sites (e.g., bone assemblages). However, the study of tooth marks on bones from a forensic point of view has received remarkably much less attention. Young et al. (2015) reinforced its importance by indicating that the analyses of bite marks might contribute to the work of forensic scientists, investigators, and police officers. It can help them in the identification and interpretation of scavengers, the condition and deposition of a set of remains, and the assessment of traumas. Some authors selected here claim that these bite mark patterns are not influenced by the carnivore`s habitat (wild or captive), so their morphological and morphometric characteristics would generally not vary (Gidna et al., 2013; Sala et al., 2014; Yravedra et al., 2017). However, we have discussed several factors that can influence these marks. Some authors argued that the study of tooth marks could be a useful tool for differentiating animal taxa. However, as early as the 1980s, Haynes explicitly or implicitly admitted the difficulty of differentiating animal taxa with a high degree of certainty using bite mark analysis on bones. Even Yravedra, et al. (2017) got ambiguous results using advanced analysis systems. The bite pattern analysis is most commonly used as a forensic identification tool in marks caused on soft tissues by using the distance between injuries caused by teeth (especially canines), shape of the dental arch, incisor tooth morphology, canine tooth morphology, and the spacing between the teeth. Nonetheless, this tool has its difficulties. Although it is also theorized that no two dental patterns are similar, some facts like the plasticity and hysteresis of the victim skin, the position and violence degree of the biting suspect can eliminate that singularity (Kling and Stern, 2018). Besides, other suspect's characteristics like size and breed (especially in dogs) can also vary the bite mark pattern (Bailey, 2016).

Although the bones are far less elastic than the skin (Bailey, 2016), as we discussed above, its degree of modification (presence and characteristics of tooth marks) are also conditioned by several factors including some which affect the skin. We must emphasize that those factors that can create distortion in the patterns and can lead to erroneous interpretations. Consequently, following the criteria stablished by ABFO (American Board of Forensic Odontology 2016) (Kling and Stern, 2018) will not allow us to exclude or not a possible suspect. This point is an essential factor in forensic investigations. Furthermore, despite the advances made in recent years, there is inconclusive evidence to distinguish with absolute certainty between the bite marks patterns caused by wolves or domestic dogs on bones beyond any reasonable doubt. Bite marks are caused by a direct contact with the victim during an attack. Hence, traces of biological or physical evidence (e.g., scats, hair, saliva, blood, etc.) are normally left on the victim or the aggressor based on the Locard's Exchange Principle. These traces must be collected and analysed (e.g., DNA analysis) (Kling and Stern, 2018) in conjunction with the bite patterns analysis to increase the probability of identifying the potential offending agent. For a correct interpretation of the teeth mark patterns, it is important to use other potential evidences. It is imperative to know the context in which they were created (Camarós et al., 2017; Gardner and Krouskup, 2019; Ubelaker and DeGaglia, 2020) as Yravedra et al. (2014) also mentioned (e.g., were them hunting, scavenging, recreational activities?). This would allow a better understanding of the type of relationship and degree of association between the findings. Many contexts are unknown in most of the selected articles, because their objectives are different to forensics.

Although the selection criteria of this review included only original full papers, it is difficult to avoid making a brief mention of Lewis R. Binford's work entitled "*Bones: Ancient Men and Modern Myths*" (Binford, 1981), which is constantly cited in articles in this field. Binford gave a detailed description of the destruction and bone modification patterns. He worked with 12,716 bone samples belonging to caribou and sheep recovered from nine Eskimo dog yards and 416 bone samples recovered from two small wolf dens. He described in detail the classical types of tooth marks and variations caused by wolves and dogs. He also described how both tooth marks and fractures are created during the feeding process establishing a link between tooth marks and consumption patterns. Burque (2013) used this methodology 32 years later. As mentioned above, Yravedra et al. (2011) considered another important factor in the results: the quantity of meat covering the bones, which had already been noted by Binford three decades earlier. One of the key factors affecting clear animal identification is tooth mark overlapping among animal taxa, which is partly a result of the methodology and/or the selected or available samples. The authors have already recognized this as a limitation in their studies. However, as seen above, each author in the papers reviewed indicated one or more variables/factors, which would explain their outcomes. Some factors are attributed to samples (e.g., density, humidity, carcasses size, muscle mass, freshness of the bones, homogeneity of the sample, *rigor mortis,* etc.); taxa (e.g., size, number of animals, behaviour, consumption strategy, feeding intensity, sex, and age); physiological condition (health or reproductive condition); external and /or environmental condition (bone exposition time, seasonal variation, availability, vulnerability, etc.); or methodology (e.g., statistics analysis). However, it seems paradoxical that several variables affecting teeth mark dimensions or bone modification patterns mentioned in the 1980s by Binford and Haynes were not considered in subsequent studies. On the one hand, we should remember that in most of the archaeological, taphonomic or paleontological investigations, the information is collected from previous researchers or, at best, directly from antique samples (sometimes hundreds of years old). These samples are often in poor condition. In this regard, it is important to note that archaeological or taphonomic studies usually depend on the availability of more than a personal selection of samples.

Furthermore, these conditions can have a negative impact on the final sampling size and consequently on the results. On the other hand, we must consider the statistical methods available in the past. To incorporate more qualitative variables in the analysis, alternative collection and analysis methods were required. In this context, among our selected authors, the most significant analysis advancements were through the use of image (Delaney-Rivera et al., 2009; Parkinson et al., 2014), geometric morphometric (Aramendi et al., 2017), multivariate statistical (Dominguez-Rodrigo et al., 2012), or a combination of those methods (Aramendi et al., 2017; Yravedra et al., 2017). From an archaeological, taphonomic or paleontological point of view, efforts for taxa identification through the study of bite marks have been remarkable. However, they are still insufficient for forensic investigations related to people and/or animals that have been attacked or bitten, or in the case of scavengers with the presence of bite marks registered on soft and hard tissues (*e.g.*, bones). The question is why this is the case, even with the new techniques described above. In a forensic context, one reason for this could be the low number of recorded human fatalities already mentioned by Murmann (2006). Furthermore, although bite marks depend on tooth morphology and size, and do not vary in the same animal, several variables can influence the final characteristics of the bite marks. For this reason, some researchers (Gidna et al., 2013; Sala et al., 2014) to cite only a few, recommended that bite mark pattern analysis must be used cautiously in specific animal taxa differentiation. This is more critical if we compare subspecies belonging to the same genus. In forensic investigations, this flexibility is important because the use and benefit of bite mark analysis is connected directly to the characteristics of the crime scene and the objectives that research should pursue. Domínguez-Rodrigo and Piqueras (2003) and Young et al. (2015) noted that bite mark analysis could not be used alone in the identification of a scavenger species due to multifactorial characteristics present during the biting process. However, under appropriate conditions, we may be able to identify the aggressor animal using bite mark analysis with a high degree of certainty (Rollins and Spencer, 1995). As has been mentioned, one of the main objectives in a forensic investigation is to identify the suspect/guilty individuals based on evidence and information collection. A greater amount of valid scientific information related to bite marks, bones, environment, etc., increases the likelihood of achieving results with a high degree of certainty. The lack of information (e.g., characteristics associated to the samples) in a forensic context can invalidate the investigation/court procedures. In addition, the inclusion of multivariate statistical analysis, geometric morphometry and the digital systems used by some of the authors mentioned allowed them to get information impossible to obtain years ago in any context (forensic, archaeological, etc.). Multivariate statistical analysis allowed them to incorporate and relate quantitative and qualitative data. This, at best, would help them to identify the variables (e.g., bite mark dimensions, type of bite mark, etc.) that make it possible to classify and categorize the evidence (e.g., suspects or authors of bite mark) with a higher reliability. Nonetheless, the relative statistical error in an archaeological, paleontological and taphonomic context may be counted in years or centuries, which in a forensic investigation is unusual and usually not acceptable. We can discuss the types and tooth mark dimensions obtained by the authors (Table 1) and the ranges established for wolves and dogs. However, making an in-depth comparative analysis of them would be merely referential in a forensic context, unless there is a bite mark database generated using a standardized process. This would be useful for comparing evidence found on the "crime scene" and to determine the agent responsible. This can be quite difficult due to many variables mentioned previously that intervene in the biting process. For this reason, multidisciplinary work (by archaeologists, anthropologists, photographers, forensic dentists, veterinarians, ethologists, etc.) is of critical importance in forensic investigations. In a previous work (Haglund et al., 1988) on human remains, the scene observations were augmented with reports written by the police, physical anthropologists, and the medical examiner's office. Undoubtedly, this information, although it comes from multiple sources, is extremely valuable. As such, it should allow forensic investigators (veterinarian and medical examiners) to gain a more holistic view and understanding of the problem and to reduce the field of suspects. Insufficient expertise (Williams and Johnston, 2004) and unreliable methods (Cozza et al., 1996) often make it difficult to achieve a successful identification of the animals responsible (wolves or dogs). Consequently, wolves have been blamed without the slightest scientific and technical support, and compensations have been unfairly paid. It should also be noted that wolf or dog attacks on humans are not uncommon (Lyman, 1994). Considering the scale of the problem, the lack of effective tools for the identification of bite marks seems strange. Most researchers have tried to differentiate animal taxa using the external or macroscopic characteristics of the bite/teeth marks. However, only a few of those works provided outcomes (Table 1, column h) that enabled, according to their authors, a precise identification of the potential aggressor, specially between large and small animals analysing (Andres et al., 2012; Parkinson et al., 2014). In that respect, Aramendi et al. (2017) have suggested interesting tools for futures studies based in new statistical test and 3D techniques (Table 1, column g) to paleontological and archaeological purposes. Yravedra et al. (2017) also used all those tools during the same year.

To identify a potential non-human aggressor (e.g., dogs or wolves) by analysing the bite mark patterns as a forensic tool, it is necessary to compare the unknown patterns (questioned evidence) found at the crime scene (predation or scavenging place) against the known bite patterns (control database). For the creation of this, so far, non-existent control database, the absent and partially analysed variables included in each of the selected studies must consider and contain the bite marks patterns created in various contexts (e.g., scavenging, recreational activity).

Based on the above, this work offers the following recommendations for future forensic comparative studies of tooth marks on bones caused by wolves or dogs:

To use standardized samples, they must consider the samples type (long, short or flat bones), number, animal origin (e.g., only cows, equids, deer, etc.), physical characteristics (e.g., type, weight, size, density, age, from adult, and young animals), and place of origin. The bite mark patterns caused on the bones exposed to different environmental condition can affect the results of their study (e.g., dry, frozen or fresh bones). All types of bones covered or not with muscle mass and carcasses (articled and non-articled) must be used. The use of the largest number of samples as possible is also important for a better statistical analysis and a detailed and individual analysis of bite marks. To use more standardized predator/scavenger/attacker (dogs or wolves) according their habitat (wild or captive), nutritional and dental conditions, number of animals, age, size or weight, time for accessing bones and the breed and function of dogs (hunter`s dogs, companionship, etc.). The environmental conditions (e.g., temperature and humidity) and the reproductive condition of the animals associated to the season during the creation of the bite a mark must also be registered. In order to increase the possibilities of a more accurate identification, these same variables inherent to the aggressor, the victim and the environment must be considered during the interpretation of new attacks. Because of the high number of quantitative and qualitative variables, we propose a multivariate statistical analysis including morphology and morphometry of teeth mark (e.g., type, number, distribution, frequencies, and dimensions according to the bone region and density), and fracture features. Due to ethical issues, the studies of tooth mark analysis caused by hunting activity (attack and defence action) must be done on death and wounded animals, hence, there is total certainty regarding the aggressor agent as well as about other conditions. In practical terms, this is more difficult because after death many other animals can scavenge the corpse before the evidence are collected.

These studies will allow creating known bite patterns (gold standard bite mark patterns) in different contexts for comparing the evidence found at the site of the attack/predation or scavenging. Currently distinguishing between these two scenarios only thorough tooth mark patterns it is a big challenge (Camarós et al., 2017). The presence of only wolves or dogs tooth marks on the bones is not conclusive to blame one of the two species. For forensic investigation, it is required to determine which of them caused the death and which of the two subspecies they belong to. This implies performing a detailed and systematic analysis of the crime scene and bite marks, including any biological trace (e.g. blood, urine and saliva for DNA) in skeletal traumas complemented by histological studies of the bone lesions. This could help determining if there is evidence of vital reaction of the bone tissue created only when the damage was caused before the death (ant*emortem*) or during the attack (*perimortem*). This is particularly important in an advanced decomposition state of soft tissues (Cappella and Cattaneo, 2019). This panorama reinforces the concept of the need to work in a multidisciplinary way, carrying out exhaustive analysis of bite patterns in search of details that allow the differentiation whilst complementing the study of patterns with other evidence found in the places where the attacks occurred.

5. CONCLUSIONS

Wolves and domestic dogs can cause different types of bite marks on animal and human bone remains. Their morphological and morphometric characteristics are influenced by a number of factors that must be considered in future experimental studies (regarding samples, taxa, environment, context, and statistical methods used for analysing the results) and during the interpretation of the results. The integration of qualitative and quantitative information must be worked out using multivariate analysis. New tools are required to differentiate between wolf and dog bites with a high degree of certainty. Finally, it must be mentioned that the need for additional interdisciplinary and experimental works is unquestionable in these fields to complement and extend the scant information available.

6. Conflicts of Interest: The authors declare no conflict of interest and, this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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