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RESEARCH ARTICLE

Analysis and Identification of Damages Caused by Canine (*Canis lupus familiaris*) Manipulation of Woven Textiles as Cultural Evidence in Forensic Cases

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ABSTRACT: Scavenging of human remains by dogs can make the process of identification and analysis of perimortem trauma difficult. Numerous scientific studies have been published about the damage caused to osseous remains by dogs due to postmortem consumption or lethal attacks. However, few studies deal with the issue of the analysis of clothing associated with human remains.

The purpose of this investigation was to identify patterns of damage caused by domestic dogs to commonly used, woven textiles. Forty-five cloth bags were used (20 × 30 cm each), made by hand with three different types of woven textile (15 of each textile): stretch (polyester with elastic), denim, and polyester, with a thickness of 40.84, 57.95, and 31.46 threads per cm², respectively. The canine sample consisted of 15 dogs, differing in size, age, and sex, coming from the "Fundación Chile Mestizo," in Santiago, Chile. Through analysis of variance, researchers examined the relationship between the type of textile and presence of damage, and later, they calculated the frequency of damage according to type of textile. The statistical program Minitab 19 was used to do this. According to the results, four types of patterns were identified: puncture and mastication, present in 62% and 75% of the cases, respectively; perforation; and "hole and tear" damage in 91% of the analyzed cases. Regarding the relationship between textile type and frequency of damage, researchers found that the thickness and weight of the textile are directly connected to the type of damage.

KEYWORDS: forensic archaeology, scavenging, dogs, woven textiles, damage, thickness

Introduction

In the Human Rights Unit (UDDHH) of the Medical Legal Service (SML, *Servicio Médico Legal*), all evidence linked to judicial cases coming from the Metropolitan Region of Santiago and other regions of the national territory (an average of 68 cases per year, from 2007 to 2019) (Garrido & Intriago 2012) is analyzed. This evidence includes clothing and human remains in different states of conservation: complete, fragmented, burned, saponified, or putrefied.

In most cases, remains are found with clothing and personal accessories, which are analyzed by archaeological experts to reconstruct and identify them. These remains show damage of medicolegal interest, such as injuries from firearms or knives, signs of combustion, or scavenging activity, which complicate the identification of perimortem trauma (Colard et al. 2015). Existing studies in the scientific literature about manipulation of cadavers and human remains by animals are used as theoretical support when researchers describe marks left due to animal consumption (Coard 2007; Erkol & Hösükler 2018; Haglund et al. 1988, 1989).

Of these, dogs (*Canis lupus familiaris*) are primarily involved in cases of occasional scavenging and consumption of decomposing remains, especially in sectors of cities where trash is collected or along the banks of rivers, where dogs, alone or in a pack, scavenge the cadavers of homeless individuals, homicide or suicide victims, or remains that come from illegal burials (Haglund et al. 1989). In closed spaces, the dogs themselves may eat the remains of their owners who have died in circumstances of natural or violent death (Colard et al. 2015). The most obvious differences in both cases are the location of injuries on the corpse: in the case of attack and consumption in closed spaces, the presence of clothes and the dog's bond with its owner (Rossi et al. 1994; Rothschild & Schneider 1997), mean that the majority of injuries occur in the face, neck, and sometimes, hands. On the other hand, in open spaces, injuries to the upper and lower extremities and torso are more common. In both cases, the marks left on bones, soft tissue and skin present similar characteristics (Colard et al. 2015). Occasionally, the clothing remains

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are found separately, damaged, and without any association to biological remains.

Expert archaeological analysis of articles of clothing is very important, firstly because it can provide valuable information and orientation about the physical characteristics of the individual, including size, stature, age, and probable gender. In addition, it allows the registration and identification of damage caused by third parties, which are of medicolegal interest (Haglund 1997). In this way, archaeological expertise complements the anthropological analysis of biological remains.

Currently, studies do not exist about damage caused by dogs to clothing associated with cadaverous remains, apart from one investigation about manipulation by other carnivores; in this case, tigers (Leonov 2011). For this reason, in the archaeological analyses carried out by the UDDHH, investigators proceed from the hypothesis that there is a morphological and physical similarity between the collection of marks left by dog bites on the skin and those observed on the textiles of which the clothing is composed. In effect, the skin, because of its natural elasticity (Cua et al. 1990), can behave in a way similar to textiles used in making common items of clothing like elastane, nylon, or cotton, yielding patterns already typically documented in bone: punctures, when the force exerted by the teeth is not sufficient to perforate the cortical tissue of the bone; perforations, when the bite destroys the surface of the cortical tissue, reaching the cancellous bone; longitudinal canals; and lastly, signs of dragging or wrinkles, which leave parallel lines on the cortical tissue of the bone.

Regarding soft tissue, it is common to observe, particularly on the skin, a kind of damage called hole and tear, which corresponds to a tear caused by dragging, a result of the biting and pulling action of the dog (Colard et al. 2015; Haglund et al. 1988, 1989). In fact, when a dog bites elastic and resistant tissues like the skin, muscles, or a textile, he shakes his head causing violent twisting and breakage of the fibers that they are made of (Fonseca et al. 2015). However, in the case of textiles, damage caused can vary according to the mechanical properties of tension, twisting, friction, and flexion. At the same time, these properties change depending on the (natural or synthetic) nature of the fabric, the molecular composition of the fibers (Halsey et al. 1945; Tan et al. 1997), and the moisture of the environment to which the textile is exposed. For instance, when exposed to high levels of moisture, textiles made of natural fibers increase their resistance. In contrast, synthetic textiles are less resistant in moist environments (Meredith 1946). Finally, certain chemical treatments of natural fibers or clothing made with mixed natural and synthetic fibers can improve the mechanical properties of the articles of clothing (Ali 2001).

Resistance to tension is one of the most important properties of a woven fabric: this refers to the maximum amount of force that a textile can withstand before it breaks. Breakage is due to the application of prolonged, unstable force that varies in intensity according to the location of the force, and based on variables such as the geometry of the textile's structure, its design, the thickness of the weft and warp, and the presence of irregularities in the fibers (Mobarak Hossain 2016).

The intensity of the mechanical force that develops from a dog's bite depends on the size of the specimen and the interaction of the forces exerted by the chewing muscles (masseter, temporal, pterygoid, digastric), the maxilla and jaw bones, the TMJ, the brain and teeth, and variable dimensions and morphology. According to various studies (Dessem 1989; Miller 1993), during an attack the vertical forces of the dog bite can surpass 450 pounds per square inch ($31*10^4$ N/m^2).

The domestic dog is a carnivorous animal with omnivorous options depending on the circumstances (Koscinczuk 2017). It can consume human remains only when the flesh is relatively fresh, without marks of insect activity or signs of decomposition (Sincerbox & DiGangi 2018). Due to its diet, the domestic dog has very developed chewing muscles, especially the masseter and temporal muscles which exert strong force in the process of biting. Along with studies undertaken on two osteological collections of dog skulls (Ellis et al. 2009), researchers have observed that brachycephalic dogs present a less intense bite than that of large-sized, short-faced dogs. However, the force of the bite as measured on skeletonized skulls does not exactly reproduce the real bite. Moreover, measuring the strength of the bite in living dogs is more difficult because of the problems that arise when one tries to control the animal (Kim et al. 2018). An adult dog's permanent teeth consist of 42 dental pieces, according to the following dental formula: 2 (I 3/3 C1/1 PM 4/4 M2/3) = 42 teeth (Figure 1) (Haglund et al. 1989; Hillson 2005)

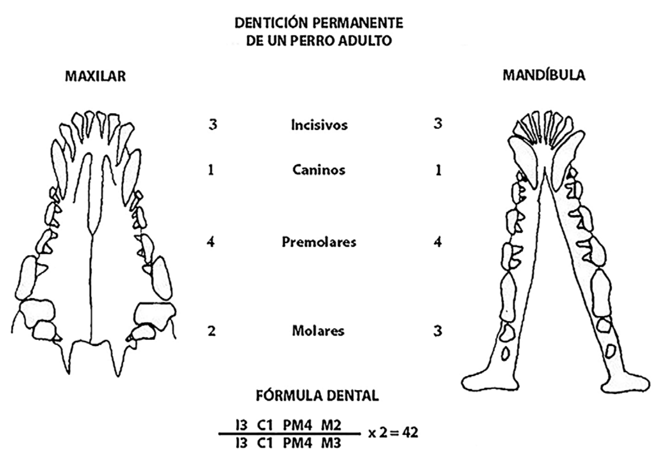

FIG. 1—*Illustration of dog's (Canis lupus familiaris) dental anatomy. Modified from Bell 1965.*

The principal objective of this study was to identify patterns of damage caused by the manipulation of street dogs in textiles commonly used, but with distinct physical characteristics: generic synthetic fabric, polyester (PET) and denim or jeans (cotton or minimal percentage of elastane). The study proceeds from the following null hypothesis (H_0): patterns in textiles like those observed in bone and human skin do not exist.

Materials and Methods

First, two initial trials were carried out at the municipal kennel in the city of La Serena in the region of Coquimbo, Chile.

For the first trial, two samples were used; one of them consistent with a long bone of a male goat, with minimal presence of dry soft tissue, and the other consisted of fresh pig legs. The remains were wrapped, but not enclosed, in light-colored, denim fabric, which is a common and resistant material. The other was wrapped in a mixed, woven fabric very common in T-shirt manufacturing, made of cotton and polyester, and black in color. The dogs selected for the experiment were an older adult male and two male brother puppies.

For the second experiment researchers used denim and a mixed cotton-polyester fabric, light blue in color. The light color was chosen to facilitate the observation of marks left by the dogs. Another variable that changed was the kind of bone: remains of cow bones with connecting tissue. The dogs in the second phase were two adult females, the first called "Kuki," who was being treated for a fracture in one of her extremities, and the second, "Mangy," who suffered from canine mange or scabies. The first day, Kuki received the bones wrapped in denim and Mangy those wrapped in mixed fabric, both in unfastened cloth bags. Two days later, in a second phase, Kuki was given bones wrapped in mixed fabric and Mangy those wrapped in denim. The objective of this second trial was the comparison between the marks left by the same animal on two distinct types of fabric and the different reactions of the textile fibers.

After the trials, a final experiment was carried out for three days in the "Chile Mestizo" Foundation, located in La Pintana Commune, Metropolitan Region of Santiago. The sample formed by 45 fresh front leg bones of pigs (*Sus scrofa*) which had soft connecting tissue. This sample was chosen for the similarity between swine and human bones (Aerssens et al. 1998). Forty-five cloth cloth bags were made with three different types of woven fabric, and each one contained a bone sample: 15 polyester cloth bags, made of jersey fabric; 15 denim cloth bags, with flat gabardine stitch; 15 cloth bags made of synthetic stretch fabric. Fifteen ribbons of different colors and shapes were used as distinctive markings for each sack. The woven fabrics selected are commonly used, and in addition, make up most of the clothing that the UDDHH receives for forensic case analysis.

Before the experiment, the woven fabrics were analyzed to determine their thickness and weight, in the Research and Quality Control of Leathers and Textiles Laboratory (LICTEX, for its acronym in Spanish) of the Department of Chemical Engineering at the University of Santiago (USACH), and under the standards of control of British Standard BS EN 12127:1998, Textiles (Beever 2014). All the samples were previously photographed with a Nikon D3000 camera, with the respective labels and metric indications.

Researchers employed 15 adult, healthy dog specimens, which lived in the same area in the kennel (Table 1); in addition, dogs of different levels of disability were included. This sample was selected to represent street dogs, very abundant in the Chilean dog population, and involved more frequently in cases of consumption of human remains nationally. During the entire experimental process, the dogs manipulated the samples for a maximum of thirty minutes.

Investigators used two different forms to register their information. In the first, the dog's characteristics (age, sex, and physical features) were described; the second tracked the type and color of the ribbon of each sack.

Once the damaged textiles were recovered, and after extracting the whole or fragmented bone, the fabric samples were photographed again with labels and measurements. Afterwards, they were stored in hermetic black (Ziploc-type) plastic bags that were previously perforated to prevent moisture from developing. The plastic bags were marked and labeled according to the characteristics of the fabric, the dog that caused the damage, and the date of the experiment.

When the experimental process in the field was finalized, the fabrics were transported to the facilities of the UDDHH of the SML in Santiago. First, due to the adhesion of saliva to the organic remains, the samples were submitted

TABLE 1—*Distribution of the dog sample according to sex, age, and size.*

	Name	Age	Sex	Size
1	Leal	A	M	G
2	Bossa	A	F	G
3	Telma	A	F	G
4	Floqui	A	M	M
5	Pepo	A	M	M
6	Jabalí	A	F	M
7	Wallaby	A	M	G
8	Ema	G	F	G
9	Rolf	A	M	G
10	Flo	A	F	P
11	Ivy	A	F	P
12	Elmo	A	M	P
13	Lola	A	F	G
14	Blanca	A	F	M
15	Suki	A	M	M
16	Rayita	A	F	G

Sex: M = male; F = female
Age: A = adult; G = geriatric
Size: P = small; M = medium; G = large

to a natural drying process at a temperature of approximately 21 degrees over a period of one week inside one of the laboratories of the Unit, with artificial ventilation provided by an extraction hood. Next, the fabric samples were photographed with a Nikon D300S camera to register the damage present at the macroscopic level. Finally, through microscopic analysis with a Leica Mz16a brand stereo microscope, all damage to the 45 fabric samples were observed and photographed at different levels of magnification (7.1×–200× magnification with incorporated digital camera): 1) weft and warp; 2) fiber; and 3) tips of the fibers.

The effect of the kind of fabric on the presence of damage was determined for the statistical analysis, through the analysis of variance with the program Minitab 19. Subsequently, the frequency of observed damage was calculated by type of fabric.

The first author (GMD) conducted the observation and analysis of the damage. With respect to the researchers' level of experience, the veterinary doctor (FSG) possesses vast experience in his field, so he assisted in the observation and control of the conduct and behavior of the dogs, and in the cataloguing of information on the sample specimens. The forensic archaeologist (SDL) and the forensic anthropologist (GMD) did not have previous experience in the analysis of damage caused by canines.

However, the forensic archaeologist specializes in the analysis of ballistic and weapons damage for expert analyses of clothing in forensic cases, and as a result, he directed the methodological process of observation and analysis.

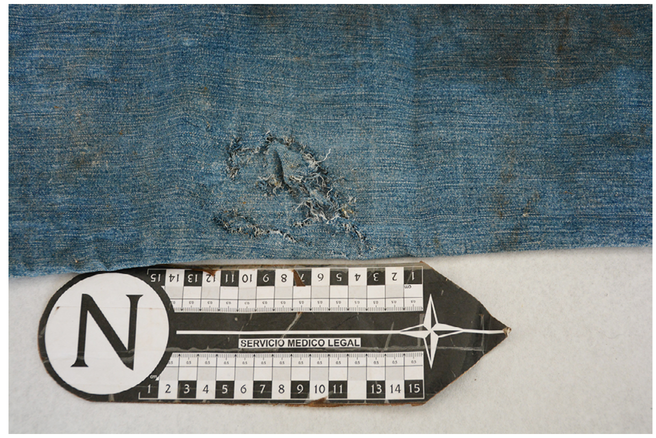

FIG. 2—*Denim sample with hole and tear damage (authors' records).*

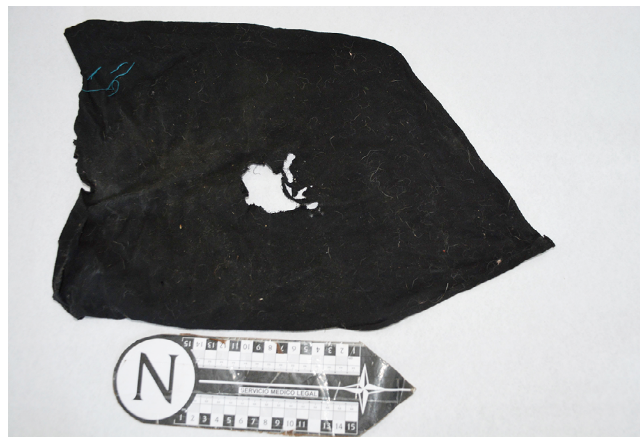

FIG. 3—*Polyester sample with hole and tear damage (authors' records).*

FIG. 4—*Denim sample with hole and tear and dragging damage (Kuki dog) (authors' records).*

Results

In the first experiment domination by the "alpha male" of the group was observed, a younger and stronger dog that violently picked up the sample but did not intervene in the fabric except to protect it. Failing to act, the denim sample was given to an older dog of medium strength, which bit the fabric, and left different kinds of marks. The second sample, a mixture of cotton and polyester was given to three mixed-race puppies: two of them left various bite and scratch marks, specifically using the upper and lower canines and the carnassials.

In the denim samples, damage such as "tab pulling," attributable to the hole and tear mechanism, and various punctures around the main damage site were observed. The visual recognition of damage to the polyester cloth was more complicated due to the dark color of the sample (Figures 2 and 3).

In the second trial, the observed damage consisted of hole and tear patterns with tab-pulling and perforations (Figure 4). Many punctures were found on the denim.

In this experimental phase it was observed that: 1) the same dog can leave different traces or marks depending on the characteristics of the woven fabric used; 2) different pairs of perforations are probably attributable to the simultaneous action of the upper and lower canine teeth; and 3) the same dog may cause pairs of perforations of different size and shape and nibbling marks due to the action of the carnassials.

During the final experimental phase, the dogs exhibited calm temperaments, but their behavior with respect to the sample was different each day. From the beginning the dominant nature of the two young, large female dogs was evident. Beyond leaving marks on their respective samples, they intimidated the other dogs to give up their samples. Similarly, there were other dogs which after the first day of experimentation did not show interest in the sample, changing the planned sequence of dogs and samples.

Regarding the thickness and weight of the woven fabrics, the synthetic stretch fabric, the fibers of which are composed of exactly equal and neat threads, with flat and simple stitches, measured 40.84 threads per cm^2 (Ali 2001). The thickness of the denim fabric was measured at an average of 57.95 threads per cm^2 and the polyester 31.46 threads per cm^2.

In the stretch fabric samples, perforations, punctures, signs of nibbling, and hole and tear damage were clearly observed. There was not major structural damage except for the presence of fraying (Figure 5).

In all the denim samples, researchers observed greater destruction of the surface, with clear alterations in shape, color, and structure of the fabric. In fact, the dogs generally required more energy to reach the piece of meat inside the sack, which was evidenced by more well-defined damage of greater severity on the entire surface and in the structural fibers. According to the morphology of the observed damage, there were six instances of typical hole and tear damage, meaning they showed a rounded appearance, of different size and always accompanied by puncture and perforation marks along with the clear fraying of the fibers on the edge of the damaged area (Figure 6). The nine remaining cases presented atypical hole and tear damage (Figure 7), with an irregular appearance, and the presence of linear tears, located on the upper and lower edges along the structure of the fabric.

Hole and tear damage were only observed in 11 polyester samples. Multiple perforations and chewing marks were observed around them (Figure 8). In accordance with the

FIG. 5—*Stretch (bistrech) sample with hole and tear and fraying (authors' records).*

FIG. 7—*Denim sample with atypical hole and tear damage, where a more linear or rectangular shaped damage may be observed (authors' records).*

FIG. 6—*Denim sample with typical hole and tear and dragging damage (authors' records).*

FIG. 8—*Polyester sample with hole and tear damage and perforations caused by nibbling (authors' records).*

results of the frequency of damage, the punctures and mastication are the least frequent damage in the samples, in 62% and 75% respectively of all the cases, while the perforation and hole and tear damage are observed in 91% of the cases studied.

Regarding the frequency of damage, perforations and hole and tear damage are the most common among all the analyzed samples (Table 2).

With respect to the relationship between type of fabric and damage, it was observed through ANOVA that the type of fabric does not influence the variance of damage described because in all the analyzed samples, the same types of damage were observed, except in the case of polyester, in which punctures were not observed (Table 3).

A clear pattern of fiber structure was not observed. The results of the microscopic analyses of the observed damage were inconclusive. It was not possible to link the different characteristics observed exclusively to specific consumption activities: fibers cut in a straight line, some ends flattened and cut, fibers with tips evened out and were cut in the shape of a heart, there were tips of fibers with clear cuts, wrinkled and folded fibers, and sharp fibers.

TABLE 2—*Distribution of damages by type of textile.*

Type of Damage	Type of Textile		
	Stretch (%)	Denim (%)	Polyester (%)
Perforations	100	80	93
Punctures	93	93	0
Hole and Tear	80	100	93
Signs of Mastication	86	46	93

TABLE 3—*ANOVA analysis.*

One-way ANOVA: Damage caused versus fabric type

Source	DF	SS	MS	F	P
Fabric type	2	2.98	1.49	0.47	0.627
Error	42	132.27	3.15		
Total	44	135.24			

Variance = 1.775; R-squared = 2.20%; Adjusted R-squared = 0.00%
DF: Degrees of freedom; **SS**: Sum of squares; **MS**: Mean squares;
F: Fisher value; **P:** P value.

Level	N.	Significance	CSE	--------+--------+--------+--------+--------
1	15	8.867	1.959	(---------------*---------------)
2	15	8.267	1.668	(---------------*---------------)
3	15	8.400	1.682	(---------------*---------------)
				--------+--------+--------+--------+--------
				7.70 8.40 9.10 9.80

CSE (Clustered standard error) = 1.775

95% individual confidence intervals for significance based on clustered standard errors.

Discussion

The focus of this research was the damage caused by dogs' manipulation of woven fabrics, a topic that has yet to be researched in the forensic literature. We defined the parameters of the study, the characteristics of the methodological design, and the variables to examine. The project benefited from the constant guidance of a multidisciplinary team of professionals in archaeology, anthropology, and veterinary medicine, who collaborated throughout the study.

The most serious challenges arose during the development of the methodological design as researchers did not have an adequate environment in which to carry out the experiments. It was not clear how to prepare a sample that would not affect the dogs' welfare, and researchers had only an approximate idea of the dog's behavior. Finally, researchers had to create a process from scratch to register information about the canine sample selected. For this reason, previous trials were fundamental to verify the guidelines of the methodology as designed.

Similarities and differences exist between the behavior of the domestic dog (*Canis lupus familiaris)* and the wolf (*Canis lupus*), determined by their shared genetics and the process of artificial and natural selection which they have undergone. For example, aggressive behavior in order to establish relations of dominance is a characteristic that wolves and dogs share (Beaver 1999). In fact, in planning the first trial, researchers did not consider the possibility of the dominant nature of a "macho" or "alpha female" emerging from the hierarchical relations inside the cages shared by various dogs (Beever 2014), a situation that created conflicts when researchers left the first sample in a cage with four dogs.

Researchers carried out the second trial a month later with two adult female specimens, each in her respective individual cage. As in the previous test, the manipulation of the fabric sample occurred very quickly, and if we treat them as isolated specimens, we can observe the mechanisms through which the dogs manipulate the samples: first, the dog begins to lick and then bite with the back teeth (premolars and carnassials) to soften the fabric, and then it manipulates the fabric with its front teeth (incisors and canines), shaking and pulling forcefully to get to the piece of meat inside. These results coincide with observations in real cases of lethal attacks and the consumption of remains in the process of decomposition (Erkol & Hösükler 2018; Feola et al. 2014).

In the final experiment in the Chile Mestizo Foundation, the behavior of the dogs varied according to the specimen and day: in general, they acted similarly in terms of the effectiveness of their manipulation of the fabric cloth bags and the patterns. However, due to the amount of space and the presence of vegetation, some dogs, upon following their predatory instinct and hunting abilities (Kherkove 2004), moved away to protect the sample and hide it among the bushes of the enclosure. This made recovering the textiles difficult given the level of dispersion (Haglund et al. 1989). Even though it was a closed space, the area was very large and the presence of dense patches of vegetation made it possible for the dogs to hide and store the sample and consume it later (Haglund et al. 1989). This behavior is very common in real cases, where dogs, wolves, or bears manipulate an animal carcass or human remains in decomposition to break them up into distinct parts, bring them to their dens, or to different locations, in order to hide and eat them (Pokines & Kerbis Peterhans 2007).

Another aspect that made the development of the final experiment difficult was the correct assignation of a specific sample to each dog. Despite using an identifying tape on each fabric sack, some more dominant dogs got a hold of other dogs' cloth bags, causing disorder that partially altered the guidelines of the methodological design. Moreover, it was observed that despite a constant supply of nourishment, and the absence of competition among the dogs for food, the specimens analyzed reacted immediately in the moment in which the sample was given. In addition, when the dogs finished manipulating the fabric and consuming the bone inside, they immediately went to the researchers to demand more samples. This confirmed the fact that especially in situations of competition among specimens, or among street dogs that lack contact with other dogs or with humans, a process of desocialization can result, which generates more aggression in the animals and less control of their stress. For this reason, most Foundation specimens were mixed-race dogs with different periods of exposure to life in the street.

With respect to the fabric samples studied, three commonly used types were selected that make up many of the articles of clothing studied by archaeological experts in judicial cases of the Medico-Legal Service of Santiago. It is worth highlighting that for this experiment, woven fabric samples and not garments were used, in contrast to real situations of manipulation by scavenging animals. All the fabrics used to make the samples, except the denim, were purchased in stores and did not show any type of previous wear and tear due to wash cycles, ironing, or use (Dann 2011).

According to the literature, domestic washing modifies the structural aspects of the textile fibers and causes progressive thinning out and loss of thickness (Carr 2017). The denim samples were made from recycled jeans. As such, the presence of wear due to everyday use and normal washing, drying, and ironing processes was noted. This permitted a greater approximation of reality for studies in forensic laboratories, in which the cultural evidence that is typically received does not correspond to fabrics that were never used, but rather mainly to entire or fragmented articles of clothing, with their respective qualitative cultural characteristics related to manufacturing (size, presence of tags, decorations, seams, clasps, and zippers), and as such with evident alterations in shape, structure and color that can change the appearance of the fibers.

In terms of the physical and mechanical properties of the woven fabrics analyzed, the relationship between the type of stitching and thickness is fundamental to bring about specific characteristics of damage. The density of the fabric, just like thickness, are the variables that determine the evident differences in damage. In effect, the densest and most resistant textiles generally show minor, but better-defined damage, because they absorb more energy, as in the case of denim (e.g., Carr 2017; Laing & Carr 2005). This is consistent with the results of this study, which demonstrated that thickness is directly proportional to the degree of deformation of the fabric and the variation of observed damage (Laing & Carr 2005). For example, the polyester samples, which are thinner than the other fabrics, showed less diversity of damage and made it more difficult to identify a specific pattern. Less thickness implies reduced resistance of the woven fabric to the dogs' actions and to a greater quantity of less diverse damage, and as such, this permitted fewer possibilities to identify patterns. Studies have shown that damage caused by knives, for instance, are more extensive and better defined in the case of new, unwashed clothing, given that they maintain their original elasticity (Cowper et al. 2015).

In this study, an analysis of clothing was carried out based on three levels of observation (Taupin & Cwiklik 2011): first, macroscopic (general quantitative and qualitative features of the woven fabric); second, weft and warp; and finally, at the microscopic level, examining the morphology of the fiber ends.

According to the results of this investigation, the null hypothesis (H_0) was rejected: the presence of clear patterns of damage was observed at the microscopic level, which is comparable with those normally observed, also at the microscopic level, on skin and bone tissue. Despite the fact that the bones used for the cloth bags were different each time, the results of both previous trials coincided with those of the final experiment: the marks on the fabric samples coincide with those described on bone tissue (punctures or perforations, signs of chewing or nibbling), while those comparable with that found in soft tissue, especially skin, correspond specifically to hole and tear damage (Byard 2016; Colard et al. 2015; Haglund 1997; Rossi et al. 1994; Schotsmans et al. 2016).

The perforations and hole and tear damage are observed most frequently, in 91% of the samples. These patterns are the result not only of the action of the animals' teeth but also its claws. In the case of hole and tear, the tab-pulling action produced by the mechanism of the dog securing the sample with the claws and pulling in the opposite direction with the incisors and canines (Figure 9) (Haglund 1997).

FIG. 9—*Process of manipulation of the sample by a dog (hole and tear damage). The dog secures the sample with a paw and pulls with the teeth (authors' records).*

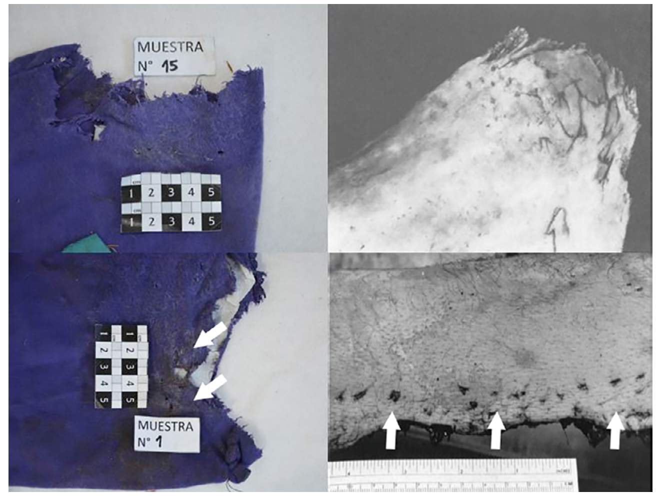

FIG. 10—*Image comparing damage caused by canine manipulation of textile samples (left); bone tissue (above right); and skin (below right). The white arrows show the chewing marks. Modified from Haglund 1997; Haglund et al. 1988.*

Due to the dimensions of the damage, its characteristic morphology and the structural deformation of the fabric, hole and tear demonstrates the most marked difference among the cases observed and can provide the most reliable illustrative information about the actor that caused it. In fact, it can be considered a diagnostic characteristic: this pattern is useful when differentiating a dog's bite from that of other animals, in which neither the shaking and pulling action nor the involvement of prominent canines occurs, as with a knife wound (Prahlow 2001). However, to cause punctures or perforations, which are normally located near more serious damage like hole and tear, the dog simply holds down the sample with its claws and digs its teeth into the fabric, in particular the canines, while to leave nibbling marks the dog, in addition to holding down the fabric with both claws, bites laterally with the carnassial molars. (Figure 10) (Feola et al. 2014).

On the skin, according to the specific kind of teeth that the dog has (20 teeth in the maxilla and 22 teeth in the jaw), the morphology of these injuries depends on the angle of the bite: if the dog bites in a lateral direction, the marks of the molars and premolars leave parallel lines, and following that a deeper incision caused by the dog. If the dog bites frontally, it causes a partially curved impression that reproduces the dental arc, causing two deep and symmetrical punctures corresponding to the canines (Colard et al. 2015; Feola et al. 2014). With respect to hole and tear damage, a puncture with a round hole is usually observed, caused by the maxillary canine or that of the jaw. It is accompanied by abrasion of the fabric and parallel linear abrasion marks, which corresponds to the action of the claws and is normally located close to the area of the bite.

In accordance with more recent archaeozoology and taphonomy studies, four categories of marks caused by dogs have been identified on bone, which have been included within the most generic category of mastication damage punctures, perforations, nicks, marks and wrinkles (Binford 1981; Lyman 1994; Pobiner 2007; Pokines & Kerbis Peterhans 2007). The first two categories of marks are normally caused by the direct pressure of the teeth exerted perpendicularly on the bone: the punctures do not usually pierce the cortical bone, while the perforations, caused by canines and carnassials, can penetrate the cortical tissue reaching the spongy tissue of the bone. The latter two categories, occurring normally in a "U" or "V" shape and found in the epiphysis of long bones, are due to the dragging action of the teeth on the bone. In addition, Erkol and Hösükler (2018) argue that different races of dogs have different size teeth, jaws, biting force and different eating habits and patterns that can affect the morphology of marks they leave on the bone.

In a study carried out by Young and collaborators (Young et al. 2015), in a sample of six deer carcasses, researchers detected the presence of punctures and wrinkles, but not of perforations on dry bones manipulated by two races of domestic dog (*Canis lupus familiaris*). The hypothesis is that, in the absence of soft tissue, tendons and muscles, domestic dogs, due also to their good nutrition, are not interested in bone marrow, biting and eating only the cortical tissue. In effect, the intensity of each mark depends on the presence of soft tissues and clothing around the bone: the teeth that leave marks more frequently are found in the front part of the dental arch (incisors and long and sharp canines) and as such, they are far from the zone of greater pressure exerted by the molars and the temporomandibular joint (TMJ). It is evident that, if the bone is still covered by skin, muscular tissues and clothing, the perforations and punctures will be more severe in the upper layers, meaning on the articles of clothing and on the soft tissues. Of course, the thickness and physical and mechanical properties of the fabrics determine the degree of intensity of the marks.

At the microscopic level, all the fibers showed, at the ends, different morphologies that do not correspond to any specific pattern of damage. Additionally, due to the low quality and lack of clarity of the image obtained at maximum enlargement (200×) in the stereo microscope, it was very difficult to differentiate the patterns and associate them to specific morphologies. This shows that, in contrast to the damage caused to fibers by the impact of a ballistic projectile (mushroom-shaped morphology), for instance, or by a cut produced by a knife (flat and thin morphology), in which it is possible to observe at the microscopic level precise patterns of behavior on the ends (Meredith 1946), with this type of damage it was not possible to link the variability of the attack or the consumption by the dog, a highly dynamic and mobile actor, to a uniform pattern of damage in the fibers. It is worth mentioning that analytical tools like the scanning electron microscope (SEM) exist (up to 50,000× enlargement) that can be very useful in examining damage in threads and fibers. However, it is also important to remember that this tool has limited usefulness in the forensic field given that it is a technique that involves the cutting and destruction of the sample; is not available in all institutions and forensic environments; is not quantitative (depending on the subjective interpretation of the observer); and finally, it cannot always provide additional information for the analysis.

Conclusions

This study has the advantage of broadening the investigation of an area that until now has not been extensively researched, that of textile analysis in the forensic field generally, and of the analysis of damage caused by dogs to articles of clothing specifically. Forty-five samples of three different types of woven textiles—synthetic stretch fabric, polyester and denim (cotton and elastane)—were manipulated by a group of fifteen mixed-race dogs (*Canis lupus familiaris*) which came from the kennel of the Chile Mestizo Foundation in Santiago, Chile. The main objective of the investigation was to determine whether patterns of damage emerged on commonly used woven fabrics for the purposes of forensic identification.

The damage patterns coincided with the scavenging or attack marks left by the dogs on soft tissue and bone, already described: punctures, perforations, hole and tear and chewing. Of these four, perforations and hole and tear damage occurred most frequently. In contrast, punctures were observed only on the stretch and denim fabrics and not on polyester, due to its low thickness. As such it can be concluded that variation in the observed damage is directly associated with the characteristics of density, thickness, and weight of the woven fabrics, and consequently with their level of structural resistance. The characteristics of the agent that causes the damage, in this case a dog, should also be considered; its weight, size, age and behavior influence the final effects on the textiles.

This study has various limitations: first, the absence of theoretical antecedents. However, carrying out two preliminary trials permitted researchers to study options, observe behaviors, and arrange details, ultimately implementing a coherent experimental design. The designed experiments were performed in controlled environments where the number of dogs present was limited, in contrast to a real setting in which large packs of dogs can cause anatomical parts or clothing fragments from the same corpse to be dispersed. As a result, it is important to consider that a series of different dogs may participate in the manipulation of a dead body in open spaces.

Second, with respect to the fabric sample, even if they were commonly used textiles, they were primarily new fabrics that had not been previously used or washed, dried, or ironed—all variables that tend to alter the original characteristics of the fabric, especially its weight and thickness. In addition, the samples were fragments, not complete garments.

One of the objectives of future investigations is primarily to incentivize professionals in the forensic field to undertake new contributions to the study of manipulation of woven fabrics by animals, particularly dogs. In addition to this, another objective is to evaluate the importance of postmortem structural alterations in the preservation of the analyzed damage.

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