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From evidence to proof: case series application of 3d reconstructions in forensic analysis of dog bite injuries☆

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ABSTRACT

The use of three-dimensional (3D) reconstruction technologies in forensic science is gaining increasing relevance for the documentation and analysis of traumatic injuries. This approach provides an innovative, non-invasive, precise, and reproducible method that is particularly well-suited for evidentiary purposes in judicial contexts.

This study presents two forensic cases of suspected death from dog attacks, in which 3D models were reconstructed to analyze bite-related injuries identified on the victims' bodies, with the aim of distinguishing them from bite marks caused by other species. Specifically, the Dexis 3600 intraoral scanner was used for data acquisition, Agisoft Metashape software was employed for photogrammetric processing and Geomagic Control X was utilized for 3D analysis. In the first case, five bite wounds were analyzed; in the second case, ten lesions were examined.

The findings demonstrate that the integration of 3D scanning and photogrammetry in forensic and forensic odontology practice can significantly enhance the accuracy of animal bite mark assessment. This integration provides objective support in both identifying the lesion typology and attributing the injuries to a specific animal species, as well as reconstructing the overall dynamics of the attack – an essential aspect of forensic expert analysis.

1. Introduction

Dog bites are a relevant global public health issue and constitute the most frequent form of injury caused by animals. While most bites result in minor trauma, severe or fatal outcomes are not uncommon [1]. In the United States, the annual incidence is approximately 12.9 cases per 10,000 individuals, with bite-related injuries accounting for around 1 % of emergency department visits.

Bite mark evidence has reached a high level of scientific reliability and is widely accepted in forensic investigations [2]. Most incidents (70–80 %) occur within domestic environments and involve the animal's owner or household member. Children are the most affected demographic group, commonly presenting injuries to the head, face and neck. A second vulnerable group includes individuals over 70 years of age, who primarily sustain injuries to the extremities [3].

Fatal dog attacks are typically characterized by repeated, uninhibited biting and the fact that the dog is unresponsive to attempts to calm it down. There are multiple possible causes, including: genetic predisposition to aggression, intact reproductive status, delayed or inadequate socialization and medical conditions such as rabies, encephalitis, brain tumors, or diabetes mellitus. Behavioral triggers such as fear (with associated warning signals often missed, particularly by children), loud voices or rapid movements may also precipitate attacks, specially in group settings [4,5].

In cases of serious or fatal injuries, forensic pathologists are required to conduct detailed assessments of the scene and injuries and to compare bite marks with the dentition of suspected animals [1].

Dog bite wounds frequently present with patterns reflecting the

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morphology of the dog's dental arches. Typical marks may include impressions of both upper and lower jaws in an oval or circular arrangement, partial patterns, or isolated punctures [6]. The quality and diagnostic value of bite marks are influenced by numerous factors, including tissue type, injury location, dynamics of the event, and anatomical features of the animal [7,8].

Bite mark comparison is complex and subject to variability. To ensure standardization, the American Board of Forensic Odontology (ABFO) has proposed specific guidelines for bite mark analysis [9]. In recent years, digital approaches, including 3D imaging and overlaying techniques, have enhanced accuracy in matching wounds to suspected dentition. Experimental studies also successfully applied 3D analysis to compare wounds to dog's dental arches [10].

Key morphometric parameters, particularly the intercanine distance, the span between the canine teeth of the same arch, are often used for identification purposes [11]. This measurement varies by skull size and breed, ranging from approximately 20–65 mm (maxilla) and 18–49 mm (mandible) [12]. However, its discriminative utility is limited in cases involving animals of the same breed and similar morphology.

This paper presents two complex forensic cases involving suspected fatal dog attacks, with the aim of emphasizing the importance of a multidisciplinary approach. Coordinated input from forensic pathology, forensic anthropology, forensic odontology, veterinary medicine and anatomical pathology is essential to accurately reconstruct injury mechanisms, assess wound morphology and support comprehensive thanatological interpretation. Such integration is particularly critical in cases where the lesion patterns require combined expertise for correct evaluation [11].

2. Materials and methods

This study examines two forensic cases in which human remains were discovered bearing lesions consistent with animal attacks, possibly by dogs or wild boars. The injuries were characterized by lacerations, avulsions and irregular wound margins, suggesting a violent and potentially multifactorial dynamic.

Case 1 involved an 85 years old male, **found dead in his garden three days after the death. During the autopsy, conducted three days later, the cause of death was attributed to a cardiocirculatory arrest due to hemorrhagic shock secondary to severe multiple traumatic injuries — including dismemberment, joint disarticulations, deep soft tissue lacerations and open fractures resulting from an attack by one or more animals, as discussed later.** Five bite wounds were identified, **raising doubts about the period of production, the vitality and the responsible animal**. Further investigations of the lesions were performed with **Dexis is 3600,** an intraoral optical scanner to scan lesions and **Geomagic Control X** for analysis and lesion measurement. **The main hypotheses regarding potential aggressors**: Cane Corso Italiano dogs, owned by a neighbor, and wild boars (*Sus scrofa*), whose presence was documented in the vicinity.

During the autopsy, cutaneous lesions were digitally recorded using an innovative 3D documentation protocol. An intraoral scanner (Dexis IS 3600), typically employed in dental practice, was adapted for forensic purposes and successfully applied to extraoral skin surfaces. This high-precision device, based on structured light technology and optical sensors, enabled real-time acquisition of the lesion morphology and the generation of full color digital 3D models.

To initiate the scanning process, a surgical glove was positioned adjacent to the wound to provide a contrasting surface, allowing the scanner to establish a reference point. After the acquisition, the glove was digitally removed during post-processing using Dexis IS ScanFlow software, which permitted selective cropping of non-relevant elements. The resulting 3D model was exported in compatible formats (.OBJ or. PLY), then subjected to morphometric analysis using *Geomagic Control X* software, which provides advanced metrological tools.

Within this software environment, it was possible to precisely identify injured areas, perform accurate measurements of wound length, width, depth and determine the inter-point distance between suspected bite marks. Additionally, cross-sections and profiles were generated to assess the morphological characteristics of the affected skin surfaces. All metric data were archived as digital images and reports, suitable for forensic documentation and comparative analysis. The scanner's high resolution enabled detailed reconstructions, providing valuable data for comparison with potential biting agents, such as the dentition of suspected animals. However, scanning was not feasible in areas that were severely mutilated or lacked anatomically recognizable landmarks, due to the intrinsic limitations of intraoral scanning technology.

A complementary photographic documentation of the lesions was also performed, using metric references to estimate, albeit approximately, the intercanine distance and canine tooth diameters. Furthermore, a forensic anthropologist conducted a biological-anthropological analysis to determine the victim's sex, age, ancestry and stature, and to identify any pathological or trauma-related findings of forensic interest.

A taphonomic assessment was also conducted, aimed at identifying post-mortem modifications affecting the remains. It is essential to distinguish between alterations resulting from environmental, climatic or biological factors, including micro and macrofauna activity and those stemming from traumatic events, whether homicidal or due to animal scavenging. Although differentiating is often challenging, contextual environmental data at the site of recovery can be instrumental in evaluating whether bone changes are attributable to natural taphonomic processes rather than perimortem trauma.

Case 2 involved a 62-year-old female, **whose death occurred inside her residence**. **During the autopsy, conducted five days later, the cause of death was attributed to hypovolemic shock resulting from multiple lacerocontusive traumatic injuries caused by animal bites, with extensive external blood loss, complicated by fat and muscle microembolism.** The body was discovered with **multiple injuries consistent with an animal attack**. The main hypotheses focused on a mixed-breed dog owned by the victim and wild boars (*Sus scrofa*), as their recent presence near the property was confirmed.

Photographic documentation of all lesions was carried out using scaled measurement tools, allowing for a preliminary estimation of intercanine distance and canine diameter. The procedure began with the positioning of the body to optimize visibility of the wounds. For metric calibration, a photographic scale was placed next to the body and included in all images, ensuring correspondence between real world and digital dimensions.

Image acquisition followed forensic photogrammetry protocols. Numerous high-resolution images were captured from multiple angles, ensuring full coverage of the lesion areas. Lighting was maintained as evenly as possible, preferably natural or diffuse artificial light, to minimize shadows and reflections that could interfere with reconstruction. Photographs were taken at a consistent distance from the subject, with 60–80 % overlap between adjacent frames, as recommended by international standards.

The collected images were processed using *Agisoft Metashape*, a software platform specifically designed for photogrammetry. The workflow included image alignment, where homologous points were identified to define the position of virtual cameras, dense point cloud generation to create 3D space, mesh construction to define lesion geometry, texture mapping using the original images and model scaling using the photographic ruler to ensure metric accuracy.

Once completed, the 3D model was exported in.OBJ or.PLY format and subsequently processed in *Geomagic Control X*. This software enabled precise mapping of lesions, detailed measurement of wound dimensions, and inter-bite spacing analysis. Cross-sections and morphological profiles were created for further assessment. All metric data were archived as digital images and reports for medico-legal and comparative purposes. Finally, the results were compared and superimposed onto positive plaster casts (upper and lower dental arches) obtained from the suspected animal's dentition by a veterinary.

3. Results

The two cases examined involve deceased individuals found in different circumstances, yet both exhibiting multiple injuries consistent with a canine attack.

In the first case, involving an 85-year-old male, the intraoral scanner Dexis IS 3600 was employed to document traumatic lesions located primarily on the scalp, face and left leg. Despite the device being designed for dental applications, it demonstrated considerable versatility in extraoral forensic use. The three-dimensional reconstruction enabled precise morphometric assessment of the wounds, allowing for accurate measurement of intercanine distance and bite mark diameter. Comparison with dental biometric data from the literature revealed a high degree of compatibility with the dentition of a Cane Corso Italiano, effectively ruling out the initially suspected involvement of wild boars (*Sus scrofa*) [13,14].

However, the scanning procedure proved ineffective in areas of severe mutilation where anatomical landmarks were absent, highlighting the operational limitations of intraoral devices when applied to highly disrupted extraoral tissues (Figs. 1 and 2).

A crucial contribution in this case came from the forensic anthropologist who analyzed bone samples collected during the autopsy. Upon arrival at the laboratory, the skeletal remains underwent systematic cleaning, photographic documentation and anthropometric measurements, followed by a detailed morphological evaluation. This protocol enabled not only accurate identification of the skeletal regions involved but also a macro and microscopic analysis of bone lesions. Clear differentiation was obtained between perimortem trauma (e.g., biting, pulling, tearing) and postmortem modifications attributable to taphonomic processes or macrofaunal activity. Direct observation of fracture patterns and surface alterations further reinforced the diagnosis of vital injury and supported the compatibility of the bone damage with the suspected dog's masticatory apparatus (Figs. 3 and 4).

In the second case, concerning a 62-year-old female found deceased in her home, forensic photogrammetry was used to digitally reconstruct the lesions in 3D. The procedure followed rigorous international standards, including high-resolution imaging from multiple angles, ≥60 % image overlap, consistent lighting conditions, and use of a metric scale for dimensional calibration. Using Agisoft Metashape and Geomagic Control X, high-fidelity and metrically accurate three-dimensional models were generated.

The wounds were primarily located on the right thigh, left arm, and scalp, the latter showing an extensive soft tissue loss. The resulting 3D model was exported in interoperable formats and subsequently compared with positive plaster casts of both dental arches from the only suspected animal, a mixed-breed dog owned by the victim, produced by a veterinary professional. Comparative analysis once again confirmed the compatibility of the injuries with the dog's dental morphology, excluding the involvement of wild fauna (Figs. 5, 6 and 7).

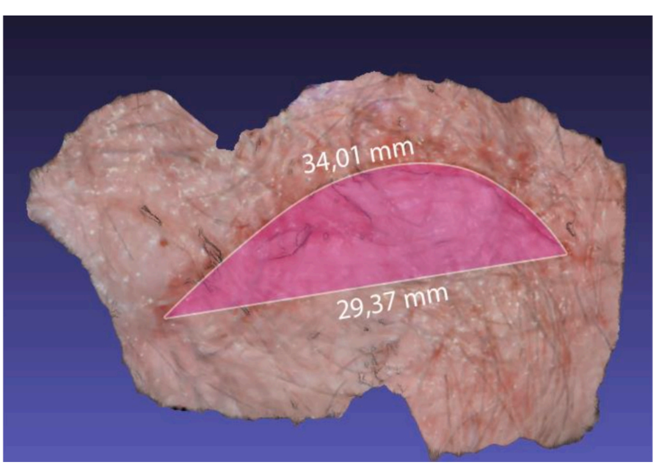

Fig. 1. Reconstruction of the injury to the scalp.

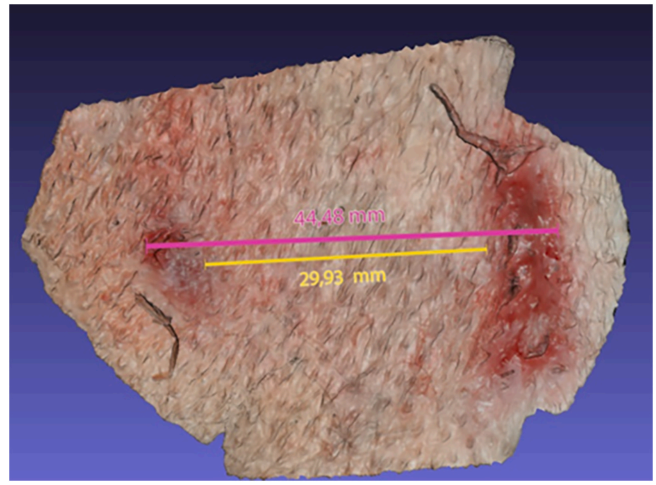

Fig. 2. Reconstruction of the injury to the left leg.

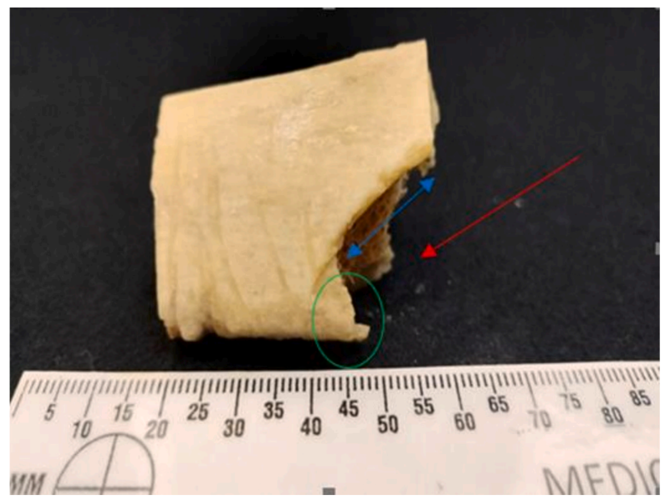

Fig. 3. Loss of bone tissue (red arrow), with a cutting surface of 1.5x2.5 cm, sharp margins at the top and slightly jagged, irregular margins at the bottom (blue segment and green circle). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Further findings of significance emerged from the histopathological analysis, which revealed the presence of both fat embolism and, notably, muscle tissue embolism. While fat embolism is a well-documented complication of severe trauma, the detection of muscular embolism is exceedingly rare and likely underreported due to diagnostic challenges and the effects of postmortem autolysis (Fig. 8) [15].

In both cases, the autopsy and histopathological data revealed definitive signs of vitality in the bite-related injuries, strongly suggesting that the attacks occurred immediately prior to death or during the perimortem phase. This finding holds substantial thanatological value, as it excludes the possibility of postmortem manipulation by animals and supports the interpretation of death as a direct consequence of the attack.

4. Discussion

The findings presented in these case series substantiate the relevance of combining 3D documentation techniques, morphometric analysis and interdisciplinary forensic expertise to accurately attribute bite injuries

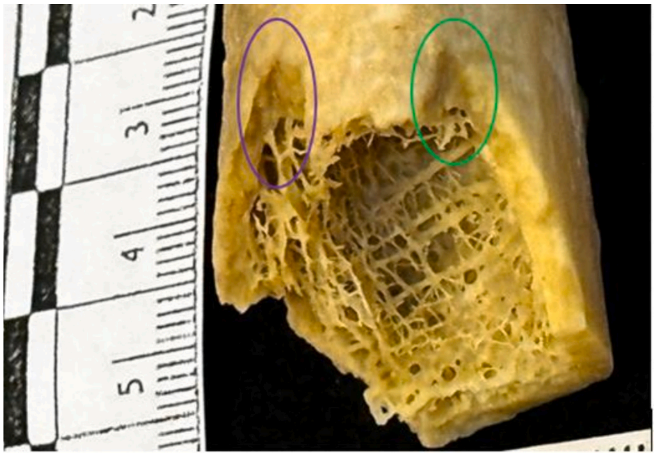

Fig. 4. Slight introflexions (purple and green circle) of triangular shape measuring 0.6x0.6x0.6 cm with the edge of the base irregular with associated loss of compact bone tissue and exposure of the underlying spongy bone tissue measuring 1.3x0.7 cm (yellow arrow) and 1.7x0.9 cm (green arrow), irregular margins. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

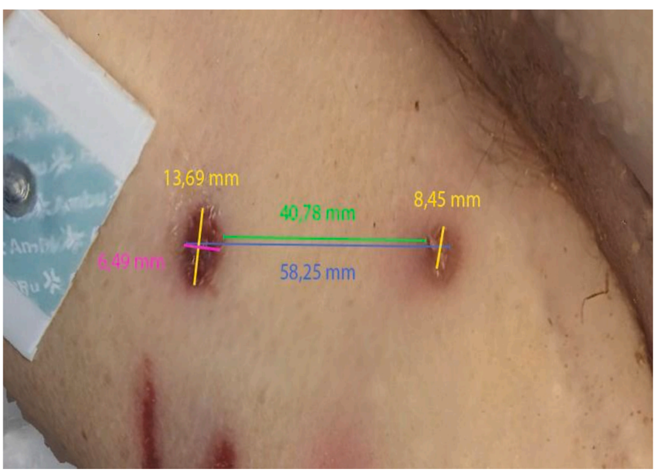

Fig. 5. Reconstruction of the injury of the left arm.

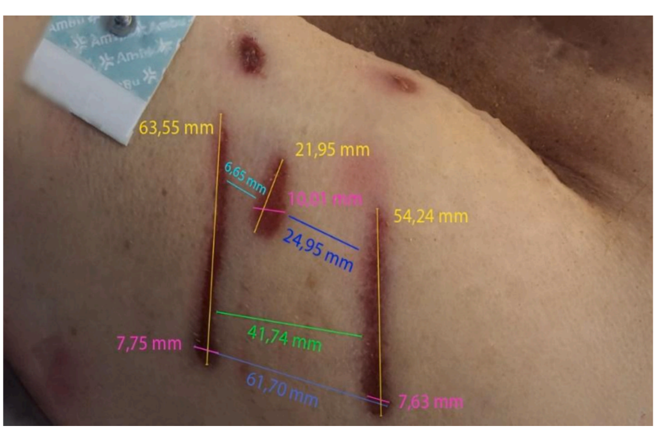

Fig. 6. Reconstruction of the injury of the left arm.

to dog attack. In the first case, the use of the Dexis IS 3600 intraoral scanner, though designed for dental applications, demonstrated exceptional adaptability for documenting non-oral wounds on the scalp, face

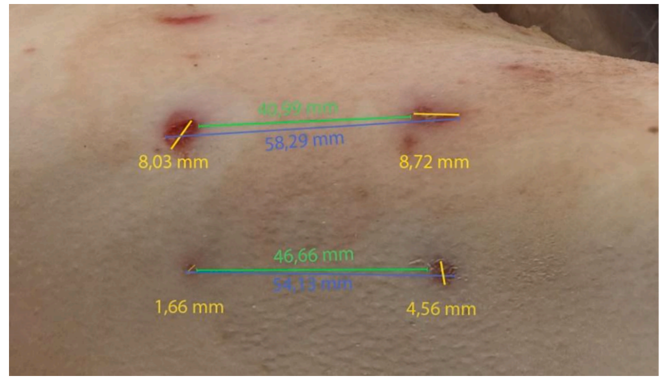

Fig. 7. Reconstruction of the injury of the right leg.

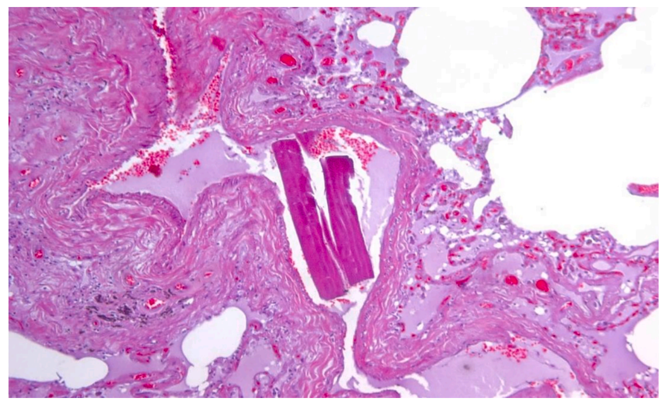

Fig. 8. Histopathological readings of slides with hematoxylin-eosin staining with relevance for the presence of micro-emboli of muscle tissue (x200 magnification).

and leg. This application aligns with recent evidence suggesting that intraoral scanners may be effectively repurposed for skin surface recording in forensic contexts, offering detailed geometric data. Particularly notable is the ability to measure intercanine distance and bite mark dimensions, facilitating comparison with published biometric datasets for the Cane Corso Italiano, consistent with established canine bite mark studies emphasizing intercanine distance as a critical identification parameter.

However, literature also warns of limitations associated with the sole use of intercanine distance, as high intra-breed similarity can reduce discriminative power [3]. These findings were mirrored in the first case, where forensic anthropological and histological examination of skeletal remains proved essential. Such analyses enabled clear differentiation between perimortem trauma, characterized by bone tearing and mechanical lesions consistent with canine dentition, and post-mortem taphonomic damage due to environmental or faunal factors, reinforcing the vitality and timing of the bite marks.

In the second case, forensic photogrammetry, conducted adhering to rigorous imaging protocols and processed via Agisoft Metashape and Geomagic Control X; delivered metrically accurate 3D reconstructions [16]. This aligns with documented forensic photogrammetry methodologies that prevent distortion artifacts associated with traditional photography and support detailed topographic comparisons between bite marks and dental models [17]. The positive dental cast comparison further confirmed compatibility with the dentition of the mixed-breed dog, conclusively excluding wild boar involvement.

The literature highlights the critical need for standardized protocols and comprehensive documentation in bite mark analysis. Some authors emphasize that canine bites often result in complex and deeply penetrating lacerations, where conventional 2D methods may fail to accurately represent dynamic injury patterns. Integrating digital 3D models and physical dental casts, as seen in both cases, supports a higher degree of evidentiary strength, providing multiple concordant points with no inconsistencies [18].

A further dimension of forensic insight emerged through histopathology. Both cases exhibited clear signs of lesion vitality and in the second case, specifically, unexpected findings of fat and muscle microembolism were documented. Micro-embolic events are acknowledged in literature as potential sequelae of high-energy trauma, though the demonstration of muscle tissue embolism is exceedingly rare and scarcely reported in autopsy studies, possibly under-recognized due to diagnostic challenges and autolysis [19].

Taken together, these findings emphasize the indispensable role of an interdisciplinary approach. Forensic pathologists, odontologists, anthropologists and veterinarians must collaborate to correlate lesion morphology, topology, biometric compatibility and histological evidence. This integrated strategy echoes best practice recommendations found in the literature, advocating for documentation of scene context, coordinated expert review and combined morphological and metrological analysis to prevent misinterpretation or wrongful attribution [20].

In summary, these two cases demonstrate that meticulous 3D documentation, combined with morphometric comparison, anthropological validation and histopathological confirmation, can achieve robust forensic conclusions on the timing and causative agent of bite injuries. This approach not only supports accurate forensic identification but also mitigates the risk of committing errors in medico-legal proceedings. Recently, experimental research has been increasingly expanded to establish intercanine distance standards based on the animal analyzed and to validate 3D methods for analyzing animal bites [18].

5. Conclusions

These case series underscore the critical value of integrating advanced three-dimensional documentation techniques with multidisciplinary forensic analysis in the evaluation of canine bite injuries. The application of intraoral scanning and forensic photogrammetry enabled precise morphometric characterization and reliable comparison with dental biometric data, facilitating an accurate identification of the causative animal species. Complementary forensic anthropology and histopathological investigations were essential to distinguish perimortem trauma from postmortem alterations and to confirm lesion vitality, thereby providing crucial insights into the timing and dynamics of the injury.

These findings highlight the necessity of a holistic and evidence-based approach in forensic investigations of animal attacks, reducing the risk of misinterpretation and strengthening medico-legal conclusions. Future research should focus on standardizing 3D imaging protocols and validating morphometric parameters across diverse canine breeds and bite scenarios, to further enhance the objectivity and reproducibility of forensic bite mark analysis.

Although this study considers only two forensic cases that occurred within a few weeks, future efforts should aim to examine multiple cases to standardize procedures and to further strengthen the multidisciplinary approach in highly complex forensic cases.

Data availability statement

The data that support the findings of this study are not publicly available due to privacy and ethical restrictions, as they contain sensitive patient-related clinical and histopathological informations. Access to anonymized data may be made available upon reasonable request.

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Informed Consent Statement: The authors waived informed consent because the Prosecutor's Office authorized all investigations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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