



A UK-based retrospective study of fatal non-drowning asphyxia cases in dogs and cats

Sean Taylor^{a,b,*}, Lorenzo Ressel^a, Paola Pregel^c, Emanuele Ricci^a

^a Department of Veterinary Anatomy Physiology and Pathology, Institute of Infection, Veterinary and Ecological Sciences, University of Liverpool, Leahurst Campus, Chester High Road, Neston CH64 7TE, UK

^b Lockgate Animal Forensics, Fell View Barn, Barrett Hill Brow, Bolton By Bowland, Clitheroe, Lancashire BB7 4PQ, UK

^c Department of Veterinary Science, University of Turin, Largo Braccini 2, Grugliasco 10095, Italy

ARTICLE INFO

Keywords:

Asphyxia
Strangulation
Choking
Hanging
Suffocation
Dog
Cat
Veterinary Forensic

ABSTRACT

Death by asphyxia is defined as the prolonged and fatal deprivation of oxygen and/or blood to the brain and other vital organs. Strangulation, smothering, hanging, drowning, choking, suffocation and chemical asphyxia are considered the main modalities in which asphyxiation can occur. The study of injury patterns is crucial for assisting veterinary forensic experts in identifying the cause and manner of death with a higher degree of certainty. A retrospective study of necropsy cases identified using the keywords “asphyxia”, “anoxia”, “hypoxia”, “strangulation”, “hanging”, “choking”, “smothering” and “suffocation” was performed. A total of 33 dogs and 16 cats were included in the study. In 67 % of cases, asphyxiation was suspected from the circumstances in which the victim was found. Whereas strangulation was the most significant modality of asphyxiation in dogs (25/33, 76 %), smothering or airtight confinement were more prevalent in cats (6/16, 38 %). Some findings that are highly indicative of asphyxiation in humans were rare or even absent in our study cohort, such as external skin bruising and fracture or dislocation of the hyoid apparatus. Most lesions were confined to head and neck, including bilateral scleral reddening, meningeal congestion, circumferential laryngeal reddening, selective subcutaneous congestion and bruising within the superficial muscles and subcutaneous tissues, consistently accompanied by severe pulmonary congestion and oedema. Whereas no single lesion was considered pathognomonic; the combination of several lesions highly indicated asphyxiation. A significant association between some lesions, the modality of asphyxiation and victim’s species was also noted.

1. Introduction

To asphyxiate is defined as killing by depriving the victim of oxygen or dying as a result of a lack of oxygen [1]. Death by asphyxiation is due to a reduction in the oxygenation of the brain tissues sufficient to disrupt brain function to the extent that causes death, achieved either by impairing blood flow to the brain or decreasing the concentration of oxygen in the circulating blood; or both. Although the brain forms only 2 % of total body weight, it receives 16 % of the total cardiac blood output and accounts for approximately 20 % of the body’s total oxygen consumption, since populated by cells with high metabolic demands and negligible turnover [2].

Since oxygen is essential for oxidative (internal) respiration within cells for their ongoing vitality, when oxygen deprivation is sufficient to cause irreversible damage, in particular to the brain stem, the result is

death of the animal due to control failure over pulmonary ventilation and cardiac output [3]. The movement of oxygen in adequate concentration from the inhaled air to the circulating blood via the capillaries surrounding the walls of the alveoli can be interrupted by several mechanisms which may also interfere with the movement of oxygenated blood from the alveolar capillaries to the blood-brain barrier. These mechanisms include absent or low oxygen concentration in the external atmosphere (vitiating atmosphere), prevention of oxygen entering the lungs by the closure of the upper airways (smothering), luminal obstruction of the larynx and proximal trachea (choking), circumferential constriction of the neck (hanging, ligature and manual strangulation), prevention of oxygen crossing the lung/blood barrier by substitution of inhaled air with water (drowning) or dramatic change in chemical composition of inhaled air (chemical poisoning) [4]. Asphyxiation may arise accidentally or as a consequence of non-accidental

* Correspondence to: Animal Forensics, Fell View Barn, Barrett Hill Brow, Bolton by Bowland, Clitheroe, Lancashire BB7 4PQ, UK.

E-mail address: UK.sean.taylor3@liverpool.ac.uk (S. Taylor).

<https://doi.org/10.1016/j.forensiint.2025.112496>

Received 27 August 2024; Received in revised form 7 May 2025; Accepted 7 May 2025

Available online 11 May 2025

0379-0738/© 2025 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

injury [5]. Animals and people are similar in that death due to asphyxia may or may not produce identifiable and characteristic pathological lesions. A study of near-hanging human patients by Berke et al. (2019) indicated that out of 98 individuals, only 8 traumatic injuries were identified. In addition, if present, the lesions may be considered to be neither sensitive nor specific indicators of asphyxiation [6]. There is an abundance of literature resources available to medical pathologists relating to the macroscopic and microscopic lesions detected in confirmed cases of death by asphyxiation in humans [7]. Conversely, pathological description of confirmed cases of asphyxiation is scarce in veterinary forensic pathology [5].

The objective of this retrospective study was to analyse post-mortem findings of dogs and cats that died due to non-drowning asphyxiation, aimed at ascertaining if any common features are associated with any specific method of asphyxiation. The study also aimed to recognise any trend or patterns in macroscopic and microscopic lesions within certain breeds or bodyweight categories and if any of the lesions commonly found in cases of asphyxiation in humans may, or may not, be expected in asphyxiation cases involving domestic animals.

2. Materials and methods

2.1. Case selection

A search of the Department of Veterinary Pathology, Institute of Veterinary and Ecological Sciences, University of Liverpool, UK database of post-mortem examinations performed between 2006 and 2023 was carried out using the following keywords: “Asphyxia”, “Strangulation”, “Choking”, “Smothering”, “Hanging”, “Suffocation”, “Hypoxia” and “Anoxia”. Only necropsy reports that had iconographic documentation of sufficient quality to retrospectively confirm asphyxiation as the mechanism of death were included in the study. Cases involving chemical or toxic causes of asphyxiation were excluded together with drowning due a more complex pathogenesis, often with a mixture of injury types.

Within the reports, circumstantial information and the signalment of each animal was recorded in terms of species, breed, sex, age, bodyweight and body condition at the time of death. Each necropsy report was analysed alongside a set of digital photographs produced by the examining pathologist at the time of the post-mortem examination, which collectively comprised the material to be analysed for each case.

The main focus of the analysis was on the gross description and appearance of each organ or tissue, with the exception of the lungs, in which a histological analysis was also taken into consideration to identify as alveolar oedema, emphysema and/or haemorrhage. The bodyweight of all but three animals included in this study had been recorded during the post-mortem examinations. Dogs were further categorised into small (≤ 10.0 Kg), medium (10.1 – 25.0Kg) and large (>25.0 Kg) breeds.

2.2. Scoring system

For the purpose of scoring, the body was divided into several regions: Head, Neck, Thorax, Abdomen, Pelvis and Limbs. Each region was then analysed for the presence or absence of pre-determined pathological lesions within associated structures (see Table 2). The pre-determined lesions included (but were not limited to) abrasions, congestion, haemorrhage/bruising, oedema, fracture, and pulmonary emphysema. For statistical purposes, data were collected in an Excel® spreadsheet and the value “0” was assigned if a particular pathological lesion was absent, while “1” if present.

2.3. Statistical analysis

The analysis was performed using Excel and GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts USA,

www.graphpad.com). In addition to descriptive statistics for the prevalence of individual findings, the presence of any statistical association among categorical parameters and species or mode of death was evaluated by Fisher’s exact test. The Kruskal-Wallis test was utilised to test continuous data. A value of $p \leq 0.05$ was considered statistically significant.

3. Results

A database search on approximately 1500 necropsy reports returned a total of 74 dogs and 30 cats, which had at least one of the keywords used within the report’s conclusion. Cases in which a post-mortem diagnosis of asphyxiation could not be reliably confirmed were excluded. All cases had information relating to the circumstances within which the animal had been found, and the detail of this circumstantial information was variable in each case, although 67 % (33/49) of cases contained information that was considered relevant to predict the cause of death. A final total of 49 animals, comprising 33 dogs and 16 cats, were included in the study.

In dogs (Table 1), the most prevalent modality of asphyxiation was strangulation (25/33), followed by choking (5/33) and hanging (3/33). Sex predilection was only noted in cases of choking, which was exclusively observed in male dogs. Eight out of 25 dogs deceased by strangulation were either Staffordshire Bull Terrier or Bull-type breeds. There were more entire dogs asphyxiated than neutered dogs in a ratio of 4.5:1.

In cats (Table 2), instead, smothering was the most prevalent modality of asphyxiation (6/16), followed by strangulation (4/16) and suffocation (4/16), and, finally, choking (2/16). Equal numbers of each sex were noted in all modalities of asphyxia under examination, even if entire cats (14) appeared to be more frequently victims of asphyxiation than neutered ones (2), in our cohort. In 3 out of 4 cases of suffocation in cats, the vessel in which the animal was forcefully enclosed and discovered deceased was a washing machine, which did not appear to have been turned on.

There was a statistically significant association ($p < 0.0001$) between the modality of asphyxiation and species. While both dogs and cats were asphyxiated by strangulation and choking, only dogs were asphyxiated by hanging. In contrast, only cats were found to have been smothered or suffocated within an enclosed vessel.

For both dogs and cats, no statistically significant associations were evident between the mode of asphyxiation and the victim’s sex, body condition, age or body weight. This was also found to be the case regarding crime scene information relating to cats, in which no statistically significant association was evident between the mode of asphyxiation and the circumstantial evidence gathered from the crime scene. However, this was not the case for dogs. A statistically significant association ($p < 0.01$) was evident between a conclusive diagnosis of death by strangulation in dogs and the corroborating information provided by witness statements and/or the crime scene.

As expected, the head, neck, and thorax were the areas most affected by pathological changes in confirmed cases of asphyxia (Table 3).

Within the region of the head, diffuse meningeal congestion, bilateral scleral hyperaemia, and selective reddening of the subcutis with the presence of bruises or pinpoint petechiae over the fascia were frequent and relevant lesions. Aside from the meningeal congestion, which was detected in most modalities of asphyxiation, ocular and subcutaneous alterations appeared most commonly in cases of strangulation and hanging.

In strangulation cases, a statistically significant association ($p < 0.01$) was noted between species showing the presence of generalised selective reddening of the subcutis of the head, with dogs significantly more likely to show this lesion than cats. On the other hand, cats were statistically more likely ($p < 0.04$) to show focal bruises of the muscles on the head.

Within the region of the neck, the most common alterations were

Table 1
Modalities of asphyxiation in canine cases.

DOGS	Breed	Sex	Age (months)	Supporting circumstantial information	Body condition	Bodyweight (Kg)	Asphyxia category
	SBT	F	3	No	Good	4	Strangulation
	Kerry Blue	M	24	Yes	Good	19	Strangulation
	SBT	M	24	Yes	Good	19	Strangulation
	Spaniel	F	NR	Yes	Good	21.9	Strangulation
	Crossbreed	M	NR	No	Good	1.23	Strangulation
	Jack Russel Terrier	M	12	Yes	Good	6.5	Strangulation
	SBT	F	NR	Yes	Good	23.2	Strangulation
	Akita	FN	84	No	Average	30	Strangulation
	Collie	M	NR	Yes	Good	16.5	Strangulation
	Bull Breed	F	NR	Yes	Good	22.8	Strangulation
	Bichon Frise	M	108	Yes	Overweight	13.3	Strangulation
	Labrador	M	60	No	Good	25.6	Strangulation
	Labrador	M	NR	Yes	Good	35	Strangulation
	SBT	F	60	Yes	Average	15.75	Strangulation
	Terrier	F	NR	No	Good	11	Strangulation
	Crossbreed	M	NR	Yes	Good	18.2	Strangulation
	NR	M	NR	Yes	Good	NR	Strangulation
	Crossbreed	FN	120	Yes	Good	19	Strangulation
	Terrier	F	NR	No	Good	11	Strangulation
	SBT	MN	NR	Yes	Good	24	Strangulation
	Border Collie	FN	NR	No	Good	15	Strangulation
	Dalmatian	F	10	Yes	Good	25	Strangulation
	Crossbreed	M	8	Yes	Good	NR	Strangulation
	SBT	F	NR	No	Good	35.8	Strangulation
	SBT	M	24	Yes	Average	16.2	Strangulation
	Terrier	M	120	No	Good	10.6	Choking
	German Shepherd	M	NR	No	Good	27	Choking
	French Bulldog	MN	84	Yes	Overweight	11.6	Choking
	French Bulldog	MN	12	No	Good	10.5	Choking
	Fox Red Labrador	M	36	Yes	Good	22	Choking
	Crossbreed	F	12	Yes	Good	23	Hanging
	Crossbreed	M	12	Yes	Good	5.15	Hanging
	Mastiff	F	NR	Yes	Good	33.4	Hanging

F: Female, M: Male, FN: Female neutered, MN: Male neutered, NR: Not recorded.

Table 2
Modalities of asphyxiation in feline cases.

CATS	Breed	Sex	Age (months)	Supporting circumstantial information	Body condition	Bodyweight (Kg)	Asphyxia category
	DSH	F	NR	Yes	Good	1.9	Smothering
	DSH	F	15	Yes	Good	3.2	Smothering
	NR	F	NR	No	Good	3.9	Smothering
	DSH	M	NR	Yes	Good	3.7	Smothering
	DSH	M	8	Yes	Good	2.66	Smothering
	DSH	M	3	Yes	Good	1	Smothering
	DSH	M	6	No	Good	2.9	Strangulation
	DSH	M	6	Yes	Good	1.25	Strangulation
	DSH	F	4	No	Good	NR	Strangulation
	DSH	F	4	No	Average	1.4	Strangulation
	DSH	F	NR	Yes	Good	2.1	Suffocation (enclosed vessel)
	DSH	MN	12	Yes	Good	5	Suffocation (enclosed vessel)
	DSH	F	10	Yes	Good	1.6	Suffocation (enclosed vessel)
	DSH	M	10	Yes	Good	1.7	Suffocation (enclosed vessel)
	DSH	M	7	No	Poor	0.9	Choking
	DSH	FN	120	Yes	Good	5.6	Choking

F: Female, M: Male, FN: Female neutered, MN: Male neutered, NR: Not recorded.

observed in cases of strangulation and hanging. They were represented by a circumferential reddening of the larynx, neck muscles and subcutaneous haemorrhages.

Apart from the lungs, fewer overall lesions were noted in the chest, abdominal, pelvic, and limb regions than in the head and neck.

In 61 % of all canine cases, the eyes showed bilateral scleral or conjunctival haemorrhages, while these were less frequent in cats (44 %). Among the total of 4 dogs (3 strangulations and 1 hanging) classed as a small breed (<10Kg), only 1 (25 %) strangled dog showed bilateral scleral and/or conjunctival haemorrhages. This compared with a total of 27 dogs over 10 kg, in which 18 (67 % - 16 strangulation and 2 hanging cases) showed bilateral and/or conjunctival haemorrhages (Table 4).

Exophthalmos was observed in 6 of the 49 cases (12 % - 4 dogs and 2 cats) and 5 of which (83 %) were due to strangulation.

Diffuse meningeal congestion was evident in 63 % of all animals. Within the chest wall region, pathological changes were mostly represented by single or clusters of bruises over the dorsal midline of the thorax.

A dorsal midline cluster of bruising within the subcutis of the chest was noted in 18 % of cases. However, strangulation (7/9) was the most dominant method of asphyxiation associated with such a change, compared with hanging (1/9) and smothering (1/9). Suffocation and choking did not show any evidence of a dorsal midline cluster of bruising over the region of the chest.

Acute rib fractures were noted in 1 dog, while no rib fractures were

Table 3
Pathological lesions found for each modality of asphyxiation.

	Strangulation (n = 29)		Hanging Dogs (n = 3)	Choking (n = 7)		Smothering Cats (n = 6)	Suffocation (enclosed vessel) Cats (n = 4)
	Dogs (n = 25)	Cats (n = 4)		Dogs (n = 5)	Cats (n = 2)		
Head							
Skin - Abrasion/laceration	8 (32 %)	0 % (0 %)	1 (33 %)	3 (60 %)	0 (0 %)	1 (17 %)	0 (0 %)
Subcutis - Generalised selective reddening	23 (92 %)	1 (25 %)	2 (67 %)	3 (60 %)	0 (0 %)	4 (67 %)	0 (0 %)
Subcutis - Bruising	18 (72 %)	3 (75 %)	2 (67 %)	1 (20 %)	0 (0 %)	4 (67 %)	2 (50 %)
Muscles - Petechiae	1 (4 %)	1 (25 %)	1 (33 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Muscles - Focal Bruising	10 (40 %)	4 (100 %)	1 (33 %)	0 (0 %)	0 (0 %)	2 (33 %)	2 (50 %)
Eyes - Bilateral scleral/conjunctival haemorrhages	18 (72 %)	3 (75 %)	2 (67 %)	0 (0 %)	0 (0 %)	3 (50 %)	1 (25 %)
Eyes - Exophthalmos	4 (16 %)	1 (25 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (17 %)	0 (0 %)
Lips & Tongue - Dotted bruises	9 (36 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	4 (67 %)	1 (25 %)
Nasal Cavity - Epistaxis	6 (24 %)	3 (75 %)	1 (33 %)	1 (20 %)	0 (0 %)	2 (33 %)	3 (75 %)
Meninges - Diffuse congestion	19 (76 %)	3 (75 %)	3 (100 %)	3 (60 %)	0 (0 %)	4 (67 %)	1 (25 %)
Neck							
Skin - Abrasion	5 (20 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	1 (17 %)	0 (0 %)
Skin - Bruise	7 (28 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (17 %)	1 (25 %)
Subcutis - Confluent petechiae	11 (44 %)	3 (75 %)	0 (0 %)	1 (20 %)	0 (0 %)	2 (33 %)	0 (0 %)
Muscles - Petechiae & ecchymosis	15 (60 %)	4 (100 %)	2 (67 %)	0 (0 %)	0 (0 %)	4 (67 %)	0 (0 %)
Larynx - Circumferential reddening	13 (52 %)	2 (50 %)	2 (67 %)	1 (20 %)	1 (50 %)	2 (33 %)	0 (0 %)
Hyoid - Fracture/dislocation	1 (4 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Thorax							
Subcutis - Bilateral cluster of bruises	2 (8 %)	0 (0 %)	1 (33 %)	1 (20 %)	0 (0 %)	0 (0 %)	0 (0 %)
Subcutis - Dorsal midline cluster of bruises	7 (28 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	1 (17 %)	0 (0 %)
Muscle - Monolateral cluster of bruises	5 (20 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (17 %)	1 (25 %)
Muscles - Dorsal midline cluster of bruises	2 (8 %)	1 (25 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (17 %)	0 (0 %)
Thoracic Cavity							
Bilateral haemothorax	4 (16 %)	1 (25 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (17 %)	1 (25 %)
Lung - Severe diffuse congestion	21 (84 %)	3 (75 %)	2 (67 %)	4 (80 %)	0 (0 %)	5 (83 %)	4 (100 %)
Lung - Alveolar oedema	23 (92 %)	4 (100 %)	3 (100 %)	4 (80 %)	2 (100 %)	5 (83 %)	3 (75 %)
Lung - Alveolar haemorrhage	17 (68 %)	1 (25 %)	3 (100 %)	1 (20 %)	0 (0 %)	5 (83 %)	1 (25 %)
Lung - Alveolar emphysema	7 (28 %)	1 (25 %)	1 (33 %)	0 (0 %)	1 (50 %)	1 (17 %)	0 (0 %)
Trachea - Bruising over Trachealis muscle	7 (28 %)	0 (0 %)	2 (67 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (25 %)
Abdomen & Abdominal cavity							
Serosa (visceral & parietal) - Diffuse serosal congestion	1 (4 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Kidney - Congestion	14 (56 %)	1 (25 %)	3 (100 %)	1 (20 %)	0 (0 %)	3 (50 %)	2 (50 %)
Pelvic Cavity							
Perineal region - Faecal soiling	2 (8 %)	1 (25 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (25 %)
Thoracic Limbs							
Claws - Irregular wear/fraying	2 (8 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	2 (33 %)	1 (25 %)
Subcutis - Selective intense reddening	0 (0 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Pelvic Limbs							
Claws - Irregular wear/fraying	1 (4 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	1 (17 %)	1 (25 %)
Subcutis - Selective intense reddening	0 (0 %)	0 (0 %)	1 (33 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)

evident in any of the other remaining 48 cases.

In 82 % of canine cases dead by asphyxia (27/33), the lungs were severely and diffusely congested, with 91 % of canine cases (30/33) showing alveolar oedema. In cats, 75 % (12/16) showed severe diffuse congestion of the lungs, with 88 % (14/16) showing alveolar oedema. Alveolar haemorrhage was noted in 64 % (21/33) of canine cases, which appeared less common in cats (44 %).

When considering the body weight of strangled dogs, a few of the pathological changes showed a differential prevalence correlating with the animal's size, although these were not statistically significant. Alveolar haemorrhage was visible in 100 % of small breeds (<10 kg) cases (4/4), in 52 % of cases (12/23) of medium breeds (10 – 25Kg) and in 57 % of cases (4/7) involving large breeds (>25Kg) (Table 3). Similarly, within our study cohort the presence of renal congestion seemed to decrease with an increase in body weight (100 % small breed, 63 % medium breed and 0 % large breed). Conversely, a focal bruise of the *trachealis* muscle appeared more commonly with increasing bodyweight of the dog (0 % small breed, 31 % medium breed and 50 % large breed), as did those showing scleral or conjunctival congestion/haemorrhage (25 % small breed, 57 % medium breed and 86 % large breed).

Faecal soiling of the perineum was found in 33 % of all cases but was more common in dogs (27 %, 9/33) than cats (13 %, 2/16).

Fraying or fracture of the claws was not a common feature in any of

the cases included in this study. In 3 cases of hanging, just 1 case showed selective intense reddening of the subcutis associated with both the fore and the hind limbs.

Asphyxiation by choking was noted in 7 cases. In each case, choking was caused by occlusion of the proximal airways due to the accidental inhalation of ingested food or a foreign body lodged within the larynx. Apart from the observation of superficial cutaneous abrasion in 60 % of dogs (3/5), choking showed the least number of alterations in the region of the head ($p = 0.02$). Bruising of the subcutis of the head was evident in just 14 % (1/7) of choking cases in contrast to 70 % (21/30) of strangulation cases and 67 % (2/3) of hanging cases.

This trend also continued throughout the other regions of the neck, chest and abdomen with a distinct paucity of pathological lesions in cases of choking. Despite a lower incidence of cutaneous and muscular changes beyond the region of the head, alveolar oedema was similar in prevalence to other modalities of asphyxiation. Choking produced severe diffuse congestion of the lungs in 80 % of dogs (4/5) but was completely absent in cases of choking in cats.

4. Discussion

In the present study, we analysed a sample of 49 animals (dogs and cats) submitted for post-mortem examination and confirmed to have

Table 4
Pathological lesions found in strangled dogs, according to body weight category.

	Dogs		
	< 10Kg (n = 3)	11–25Kg (n = 16)	> 25Kg (n = 4)
Head			
Skin - Abrasion/laceration	0 (0 %)	7 (44 %)	1 (25 %)
Subcutis - Generalised selective reddening	3 (100 %)	15 (94 %)	3 (75 %)
Subcutis - Bruising	2 (67 %)	11 (69 %)	3 (75 %)
Muscles - Focal bruising	0 (0 %)	8 (50 %)	1 (25 %)
Eyes - Bilateral scleral/conjunctival haemorrhage	1 (33 %)	12 (75 %)	4 (100 %)
Lips & Tongue - Dotted bruises	0 (0 %)	7 (44 %)	1 (25 %)
Nasal Cavity - Epistaxis	2 (67 %)	3 (19 %)	1 (25 %)
Meninges - Diffuse Congestion	3 (75 %)	12 (75 %)	4 (100 %)
Meninges - Haemorrhages	2 (67 %)	2 (13 %)	0 (0 %)
Brain - Petechial haemorrhages	1 (33 %)	0 (0 %)	0 (0 %)
Neck			
Skin - Bruise & abrasion	0 (0 %)	6 (38 %)	1 (25 %)
Subcutis - Confluent petechiae	1 (33 %)	8 (50 %)	2 (50 %)
Muscles - Petechiae & ecchymosis	0 (0 %)	12 (75 %)	2 (50 %)
Larynx - Circumferential reddening	1 (33 %)	9 (56 %)	2 (50 %)
Hyooid - Fracture/dislocation	0 (0 %)	1 (6 %)	0 (0 %)
Thorax			
Subcutis - Bilateral cluster of bruises	0 (0 %)	1 (6 %)	1 (25 %)
Subcutis - Dorsal midline cluster of bruises	0 (0 %)	6 (38 %)	1 (25 %)
Muscles - Monolateral cluster of bruises	0 (0 %)	3 (19 %)	2 (50 %)
Muscles - Dorsal midline cluster of bruises	0 (0 %)	2 (13 %)	0 (0 %)
Thoracic cavity			
Bilateral haemothorax	0 (0 %)	3 (19 %)	0 (0 %)
Lung - Severe diffuse congestion	3 (100 %)	14 (88 %)	2 (50 %)
Lung - Alveolar oedema	3 (100 %)	15 (94 %)	3 (75 %)
Lung - Alveolar haemorrhage	3 (100 %)	11 (69 %)	1 (25 %)
Lung - Alveolar emphysema	1 (33 %)	4 (25 %)	1 (25 %)
Trachea - Bruising over Trachealis muscle	0 (0 %)	5 (31 %)	2 (50 %)
Abdomen & Abdominal cavity			
Serosa (visceral & parietal) - Diffuse serosal congestion	0 (0 %)	1 (6 %)	0 (0 %)
Kidney - Bilateral congestion	3 (100 %)	10 (63 %)	0 (0 %)
Pelvic cavity			
Perineal region - Faecal soiling	1 (33 %)	8 (50 %)	0 (0 %)
Thoracic Limbs			
Claws - Irregular wear/fraying	0 (0 %)	2 (13 %)	0 (0 %)
Subcutis - Selective intense reddening	0 (0 %)	0 (0 %)	0 (0 %)
Pelvic Limbs			
Claws - Irregular wear/fraying	0 (0 %)	1 (6 %)	0 (0 %)
Subcutis - Selective intense reddening	0 (0 %)	0 (0 %)	0 (0 %)

died of the pathological consequences of asphyxia. Our results indicate the existence of a cohort of morphological changes that are characteristic of death by asphyxiation in domestic animals.

In human literature, asphyxia is classified into numerous sub-categories based on the specific mechanism underlying the restriction of blood oxygenation of the brain [4]. In veterinary forensic investigations, most classifications are inspired by the “translation” of findings from the human literature into the veterinary context. Standardisation of definitions has been proposed [4] and for this study five broad classifications of asphyxiation have been adopted relevant to our findings: strangulation, hanging, choking, smothering and suffocation within a closed vessel.

The circumstantial information within which the animal had died relevant to the cause of death was provided in 67 % (33/49) of cases. This was particularly significant in cases of strangulation in dogs and often aligned with the conclusion of the post-mortem examination, highlighting the positive role circumstantial information has in the

achievement of a conclusive diagnosis. Anyway, it must be stressed that the role of the examining forensic pathologist should remain impartial, avoiding any bias derived from overzealous attention to the circumstantial information provided by the party submitting the carcass for examination.

Concerning the modality of asphyxia, we noticed a clear prevalence of strangulation in dogs with smothering and suffocation exclusively observed in cats. Behavioural and anatomical differences between the two species may explain such a difference. For example, the small and rounded profile of the feline head likely explains the prevalence of smothering over other modes of asphyxia in cats. Amongst the lesions in the region of the head in smothered cats, the high incidence of bruises over the head, including the bruises over the labial rim of the mouth, is possibly a consequence of circumferential compression of the head mediated by the constricting hand of the assailant.

The most common breeds of domestic animals in our study were found to be consistent with previously reported non-accidental injury research [8], the Staffordshire Bull Terrier and the Domestic Short Hair cat. Higher prevalence of the above breeds in our cohort is also reasoned by their popularity amongst UK pet owners [9].

Strangulation was the most prevalent mode of asphyxia, which refers to the pressure of a constricting object around the circumference of the neck leading to occlusion of vessels and possibly the airways independent from the victim's own bodyweight. It may be divided into ligature and manual strangulation. These two modalities of strangulation, despite leading to a similar outcome, are differentiated based on the object used to cause neck constriction. In the case of ligature strangulation the neck constricting force is applied by a tightening ligature, such as a rope. In the case of manual strangulation the perpetrator's hands or arms are directly used. While ligature strangulation can consistently determine the formation of linear skin abrasions on the victim's neck [7, 10], manual strangulation can be associated with discrete finger marks.

Just 17 % (5/29) of strangulation cases presented with visible mild indications of cutaneous abrasion on the neck. Differently from human victims of strangulation, dogs and cats have fur covering the circumference of the neck which may protect the underlying epidermis from damage caused by either friction or compression by objects used by the perpetrator.

Additionally, external bruising is not as commonly seen on the skin surface because a dog's skin has a reduced blood supply compared to humans [11], while natural skin pigmentation may also hamper the visibility of cutaneous bruises in both dogs and cats.

Despite only a minority of cases of strangulation presenting with morphological indications of compression and friction over the skin, detection of subcutaneous and muscular changes in the same region increased markedly after complete skinning. Bruises appeared more frequently in the cranial half of the neck and mostly on the lateroventral aspect, in correspondence with the jugular sulcus and lateral neck musculature, as a confluent cluster of petechial bleeding. Furthermore, selective reddening of the region of the head and neck became evident in most strangled dogs. Therefore, during veterinary forensic examinations, our findings illustrate the necessity to perform a complete skinning of the carcass to reveal subcutaneous evidence of the above mechanical forces (Fig. 1B and C).

From the haemodynamic point of view, the continuous or intermittent circumferential pressure around the neck often allows a minimal residual pressure of the arterial inflow with a dramatic cessation of venous outflow [6]. The above mechanism is the basis for the development of characteristic bilateral reddening of the ocular conjunctiva and meninges and the selective reddening of the subcutis of the head, which was found with comparable frequency in both dogs and cats.

Aside from superficial neck abrasions caused by friction and compression during strangulation, the bilateral conjunctival reddening appeared as one of the most frequent changes to be discerned during external examination of the cadaver, before dissection. While such a change, including lip and tongue bruises, could be observed in

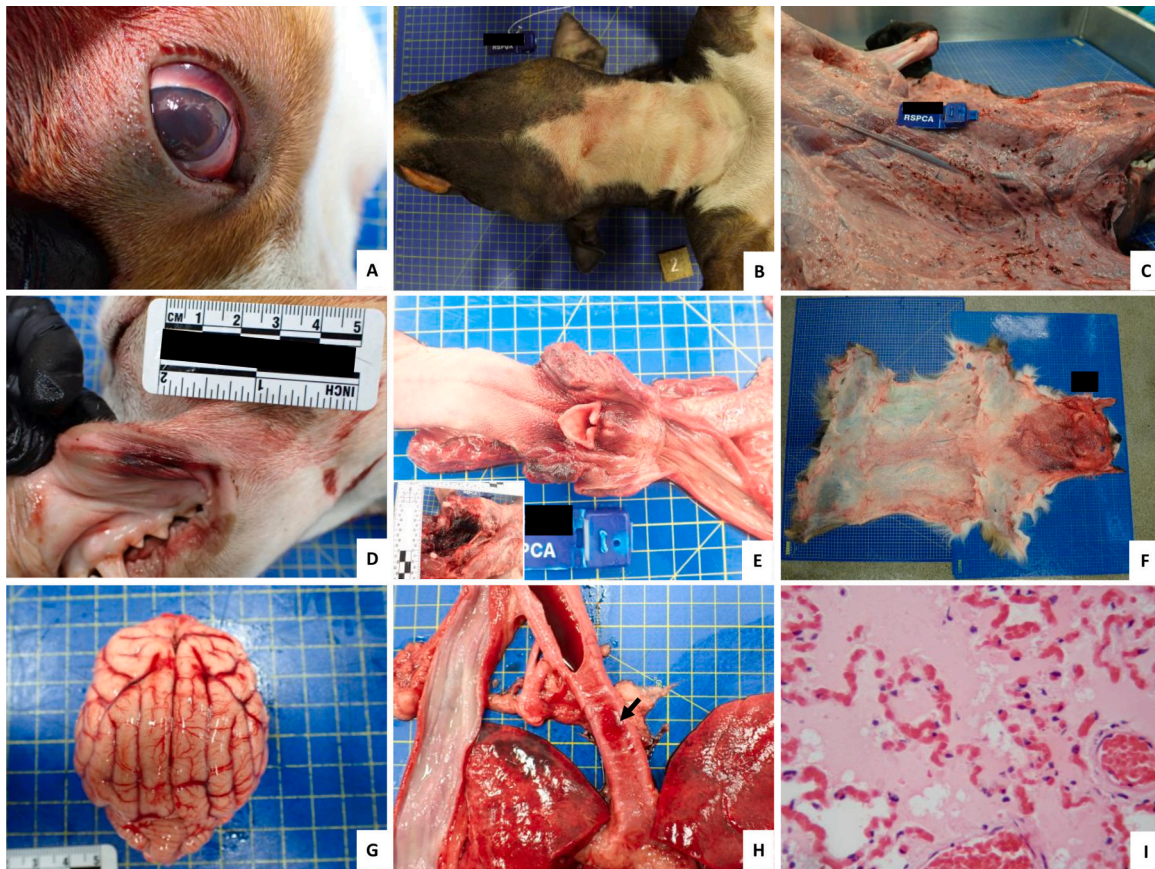


Fig. 1. Gross and microscopic findings in case of death by asphyxiation in dogs. Intense conjunctival reddening over the sclera (A). Parallel striations of “patterned” abrasions over the ventral neck (B). Confluent petechiae over the external jugular vein and scattered over the subcutis and muscle fascia of the ventro-lateral neck (C). Large bruise over the labial rim (D). Circumferential reddening of the extrinsic musculature of the larynx, also involving the soft palate, inset showing large bruise behind the larynx after partial displacement in a case of manual strangulation (E). Intense selective subcutaneous reddening over the head and neck (F). Widespread meningeal reddening with acute small leptomenigeal petechiae (G). Distal trachea of a dog showing haemorrhagic oedema within the tracheal lumen and single bruise over the trachealis muscle (arrow) (H). Panoramic view of a lung showing severe alveolar oedema and severe congestion (I), haematoxylin-eosin, 40x magnification.

generalised disorders of blood coagulation (e.g. rodenticide poisoning), the bilateral distribution of the above change may assist in ruling out the possibility of monolateral blunt force trauma to the head, where this change is commonly monolateral [7].

Haemorrhages of the sclera were found in 44 % of cats and did not appear to follow any particular trend. The affected cats had a wide range of body weight (1.0–5.0 Kg), and no particular method of asphyxiation dominated. However, in the canine cases, 20 of the 33 dogs in our study showed scleral reddening and haemorrhage, with 18 of those dogs having died due to strangulation (18 strangulation and 2 hanging). Nineteen of these dogs had a recorded body weight, with 18 dogs having a body weight greater than 10 kg.

The force applied around the neck by the average human assailant could have a greater ability to adequately occlude both arterial and venous flow so to prevent the escalation of blood pressure within the circulation cranial to the neck in a small breed dog (<10 Kg), thus reducing the likelihood of scleral and/or conjunctival haemorrhage in this cohort. Conversely, in a larger breed dog, it is considered more difficult to apply sufficient circumferential pressure to occlude completely the arterial blood flow, which causes a blood pressure increase within the ocular tissues, determining scleral and conjunctival haemorrhage. It must also be borne in mind that scleral haemorrhages have been reported in cases of non-accidental injury as a result of blunt force trauma to the head and may not only be attributed to asphyxiation [12]. It is also suggested that scleral haemorrhages can disperse and disappear in the early period after death before the pathologist examines

the cadaver as evidence [12]. Taking these factors into account, scleral and/or conjunctival haemorrhages in dogs remain a highly characteristic feature of asphyxiation. However, the study supports the assertion that an absence of scleral and/or conjunctival haemorrhages in dogs, cannot lead to the exclusion of asphyxiation as a cause of death.

In cases of suspected manual strangulation, we have noticed that the reddening and bruising are mostly on the dorsal aspect of the larynx, likely due to the pressure of the thumb of the human hand reaching the back of the larynx due to its intrinsic capacity to slide sideways when compressed [7].

Important differences in the anatomy and physiology of brain vascularisation and neck musculature between humans and domestic animals, including the quadrupedal positions in relation to the bipedal posture of the human assailant, are fundamental considerations at the core of differences in prevalence, distribution and intensity of pathological changes in cases of strangulation.

Manual strangulation of humans results in 34 % having a fractured hyoid bone and ligature strangulation produces a fractured hyoid in 11 % of human victims [13].

This study uncovered 29 cases of strangulation (25 dogs and 4 cats) and none of them had a fractured hyoid with just 1 strangled dog (representing 3 % of all strangulation cases) having dislocation of the hyoid apparatus. The low incidence of hyoid injury in our study compared to humans may be due to the superior neck length and diameter in companion animals, which allows neck compression to be effective without impinging on the hyoid bones to the degree that causes

injury. However, some forms of ligature strangulation that are applied very close to the larynx, such as a snare, are known to cause hyoid apparatus dislocations and/or fracture [12].

Bilateral haemorrhages of the lingual arteries at the base of the tongue, similar to those noted in human cases of strangulation [7], have also been occasionally and incidentally noticed in this study, but a lack of consistent documentation has led to exclusion from statistical analysis.

Within the category of strangulation, hanging was considered separately in this study, due to its characteristic mechanism of neck constriction where the force applied is due to the weight of the animal. Hanging, as a separate mode of asphyxia, is described only in dogs in our study cohort and is poorly represented (6 %, 3/49). The most characteristic changes in hanging are deemed to be the pooling of blood over distal extremities of the appendicular skeleton and caudal portion of the body. Despite predicted to occur [7], the above change was only detected in 1 out of 3 dogs confirmed to be hanged. This could be explained by the time required for the blood to create a persistent and visible pool of blood along the subcutis of the dependent portions of the body. In contrast, prominent bilateral renal congestion was detected in all hanged dogs.

Of particular interest in our study is the observation of characteristic bruising on the distal third of the trachea, where a poorly demarcated large bruise was visible over the *trachealis* muscle. Injury to the trachea in domestic small animals has been described in cases of iatrogenic damage via over-inflation of the endotracheal tube cuff during general anaesthesia, as a result of high energy blunt force trauma resulting in tracheal avulsion such as a road traffic accident and due to penetrating trauma as a result of dog bites to the neck [14–16]. However, bruising of the *trachealis* muscle does not appear to be a feature of previously reported cases of asphyxiation. We described a cat and 9 dogs having this pathology, with 7 of the dogs having a body weight of over 22.0 kg, although this was not supported by statistical significance. Aside from the observational evidence of its predominance in the large-sized dogs of our study, a putative pathogenesis could be linked to the strong and prolonged pulling of the trachea out of the cranial mediastinum when the dog is violently lifted and pulled during strangulation or hanging. All 9 dogs showing bruising of the *trachealis* were either strangled or hanged.

In human literature, the pathological changes of strangulation are often described and explained postulating a similarity in height between the victim and assailant, where the progressive constriction of the neck, either by hand or ligature material, is performed along a plane that is perpendicular to the long axis of the human body [7]. Most cases of strangulation involving domestic animals rely upon a degree of intermittent lifting of the victim's body due to their quadrupedal anatomy and lower height compared to their bipedal assailants. Furthermore, the marked volume and strength of the neck musculature and the difference in vascularization of the brain lengthen the time and increase the strength necessary for the induction of fatal asphyxiation in dogs.

The inverse correlation between the severity of the renal congestion and the dog's body weight is likely relatable to the struggle to hold the animal's neck suspended for a long period of time, which is normally necessary to induce fatal hypoxia in dogs.

Choking, determined by the total occlusion of the upper airway (e.g. laryngeal lumen), was noted in 7 cases. Although considered to be accidental in nature, the choking cases remained within the study since they provided a control, allowing comparison of pathological lesions with other modalities of asphyxiation, which are typically non-accidental in nature (strangulation and hanging). The inconsistent finding of acute superficial abrasion around the region of the face in dogs was deemed to be the consequence of self-inflicted trauma during the agonic period of asphyxia and prior to death. However, cases of fatal choking were commonly characterised by a distinct paucity of pathological alterations in the region of the head and neck, although pulmonary alterations, such as diffuse pulmonary congestion and severe

diffuse alveolar oedema were comparable to the other modalities of asphyxiation included in this study. This suggests that the occlusion of the respiratory airways during strenuous agonic attempts to expand the volume of the thoracic cavity is a sufficient condition to determine alveolar negative pressure and thus alveolar oedema and haemorrhages.

The fifth and final modality of asphyxiation considered relevant to our cohort was that of suffocation within a closed vessel, also known as environmental suffocation [7]. This was only found to have occurred in cats and was equally as prevalent as strangulation in this species. Three of the four cases of suffocation occurred by the cat having been confined within a washing machine that had not been subsequently switched on and therefore had not produced the characteristic skin abrasions and claw damaged expected via injury within a rotating washing machine drum. The remaining case of suffocation occurred due to the cat having been placed within a clothes bank, which may also have influenced the cat's death via heat exhaustion. As reported in the literature for cases of environmental suffocation [7], pathological changes are minimal and mostly restricted to generalised congestion, rendering the circumstantial information critical in determination of the cause of death.

In 67 % of analysed cases, there was discernible selective reddening of the subcutaneous tissue of the head. This manifestation was deemed to be statistically significant ($p < 0.01$) specifically in instances involving strangulation of dogs, indicating a potential shared pathogenesis with bilateral scleral reddening and haemorrhage. Nonetheless, instances of generalized selective reddening of the subcutaneous tissue of the head and diffuse meningeal congestion were also observed in cases not associated with circumferential neck constriction, such as smothering, suffocation, and choking. This suggests a plausible physiological response to hypoxia, characterized by vasodilation of cerebral blood vessels and subsequent elevation of cerebral blood flow [17].

In England and Wales under the Animal Welfare Act 2006, in Scotland under the Animal Health and Welfare (Scotland) Act 2006 and in Northern Ireland under the Welfare of Animals Act (Northern Ireland) 2011, non-accidental injury is an offence if the animal is caused to experience unnecessary suffering and, more generally, if the animal was not protected from pain, suffering, injury and disease by the person responsible for the animal's welfare. Therefore, in cases of non-accidental injury resulting in death by asphyxiation, Courts need to consider if an animal may have consciously suffered, by what mechanism and for how long. Extrapolation from human medical research in cases involving domestic animals is often not appropriate or reliable, and asphyxiation is no exception. The process of strangulation of a human, such as vascular neck restraint or 'choke hold' by direct compression of the carotid arteries and jugular veins results in a rapid disruption of cerebral perfusion and a loss of consciousness as quickly as 6–14 s [18], beyond which the person can no longer experience conscious suffering. However, research into a similar process in domestic animals shows that animals can remain conscious and experience suffering for a significantly longer period [19]. In dogs, the internal carotid arteries are less developed and the vertebral arteries provide the majority of the brain's blood supply and significant anastomoses from the external carotid arteries also guarantee a persistent blood flow to the brain despite compression [19]. In cats, the internal carotid arteries become vestigial and the brain's blood supply is heavily dependent upon epidural vessels [19]. Strangulation of the dog or cat will occlude the blood vessels of the neck, in a similar respect to those of humans, but the arterial supply to the brain has a substantial collateral structure which, despite significant forces being applied to the neck of a dog or cat, will continue to sufficiently oxygenate the brain to allow consciousness to remain for several minutes. Thus, it is reasonable to assume that during the process of strangulation (manual or ligature) and hanging, the dog or cat will experience conscious suffering via mechanisms of pain, fear, distress and panic for a period of at least several minutes, rather than several seconds as is the case for human strangulation.

The current study's limitations are mainly based on its retrospective nature having limited control over the sample population both in the

qualitative and quantitative variables. Limited statistical power resulted from the small sample size. The necropsy reports used in this study cover a 17 year period with some of the earlier dated reports having a sparse or inconsistent set of organ photographs, which hampered the identification and inclusion of a larger number of cases. Statistically significant associations were not confirmed between the modalities of asphyxiation and the victim's sex, body condition, age or body weight.

Our study shows that when certain pathological features are analysed in isolation they cannot be considered to be pathognomonic of asphyxia. However, when analysed collectively, a number of pathological features strongly suggest asphyxiation as the cause of death. These features are usually located in the head and neck regions, which may include bilateral scleral reddening, intense meningeal congestion, circumferential laryngeal reddening, selective subcutaneous congestion and bruising within the superficial muscles and subcutaneous tissues. These features are also consistently accompanied by severe pulmonary congestion and oedema. A strong statistical association between the modality of asphyxiation and the victim species was found to exist.

Our study highlighted the benefit of the forensic pathologist consistently applying a robust protocol to document post mortem findings both in written and photographic detail as well as the essential need to examine the entire subcutis of the carcase. Such an examination, in conjunction with any available circumstantial information can provide sufficient support for a reliable diagnosis of death by asphyxiation.

CRediT authorship contribution statement

Paola Pregel: Validation, Supervision, Software, Methodology, Formal analysis, Data curation. **Emanuele Ricci:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Lorenzo Ressel:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Sean Taylor:** Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of interest

The authors declare no conflict of interest.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgements

The authors are grateful and acknowledge the Dogs Trust for supporting this study via The Dogs Trust Welfare Grant.

References

- [1] B.J. McEwen, Nondrowning asphyxia in veterinary forensic pathology: suffocation, strangulation, and mechanical asphyxia, *Veterinary Pathology: U. S.* (2016) 1037–1048.
- [2] A.S. King, *Physiological and Clinical Anatomy of the Domestic Mammals*, Blackwell Science, Oxford, 1999.
- [3] S. Roberts, Diffuse cerebral anoxia and brain stem death, *Synergy* (2005) 9.
- [4] A. Sauvageau, E. Boghossian, Classification of asphyxia: the need for standardization, *J. Forensic Sci.* 55 (5) (2010) 1259–1267.
- [5] J.W. Brooks (Ed.), *Veterinary Forensic Pathology, Volume 1*, Springer International Publishing, Cham, 2018.
- [6] B.J. McEwen, Nondrowning asphyxia in veterinary forensic pathology: suffocation, strangulation, and mechanical asphyxia, *Vet. Pathol.* 53 (5) (2016) 1037–1048.
- [7] V.J.M. Di Maio, K. Molina, *DiMaio's Forensic Pathology*, CRC Press, Taylor & Francis Group, 2021.
- [8] H.M.C. Munro, M.V. Thrusfield, Battered pets': non-accidental physical injuries found in dogs and cats, *J. Small Anim. Pract.* 42 (6) (2001) 279–290.
- [9] C. Westgarth, et al., Pet ownership, dog types and attachment to pets in 9-10 year old children in Liverpool, UK, *BMC Vet. Res.* 9 (1) (2013) 102. -102.
- [10] M.J. Shkrum, D.A. Ramsay, *Forensic Pathology of Trauma*, Humana Press, 2007.
- [11] M. Merck, in: D. Merck (Ed.), *Veterinary Forensics Animal Cruelty Investigations/ Melinda*, 2nd ed., John Wiley & Sons, Inc, Ames, Iowa, 2013.
- [12] R. Munro, H.M.C. Munro, *Animal Abuse and Unlawful Killing: Forensic Veterinary Pathology*, Elsevier Saunders, New York, 2008, p. 1.
- [13] D.H. Ubelaker, Hyoid fracture and strangulation, *J. Forensic Sci.* 37 (5) (1992) 1216–1222.
- [14] R.N. White, C.A. Burton, Surgical management of intrathoracic tracheal avulsion in cats: long-term results in 9 consecutive cases, *Vet. Surg.* 29 (5) (2000) 430–435.
- [15] D.T. Lawrence, et al., Intrathoracic tracheal rupture, *J. Feline Med. Surg.* 1 (1) (1999) 43–51.
- [16] K.L. Walters, R.C. Knight, Diagnosis of a tracheal tear by use of an oxygen analyzer in a dog with cervical trauma, *J. Am. Vet. Med. Assoc.* 259 (8) (2021) 880–884.
- [17] R.J. Traystman, R.S. Fitzgerald, S.C. Loscutoff, Cerebral circulatory responses to arterial hypoxia in normal and chemodenergated dogs, *Circ. Res.* 42 (5) (1978) 649–657.
- [18] S.J. Stelpflug, et al., There is more to the mechanism of unconsciousness from vascular neck restraint than simply carotid compression, *Int. J. Neurosci.* 130 (1) (2020) 103–106.
- [19] E. Boghossian, et al., Respiratory, circulatory, and neurological responses to hanging: a review of animal models, *J. Forensic Sci.* 55 (5) (2010) 1272–1277.