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**INDICATIONS FOR TRANSFUSION PRACTICE IN TRAUMATIZED DOGS AND
CATS: A RETROSPECTIVE STUDY OF 201 CASES
(2023– 2026)**

**INDICAZIONI ALLA PRATICA TRASFUSIONALE NEL CANE E NEL GATTO
TRAUMATIZZATI: UNO STUDIO RETROSPETTIVO SU 201 CASI
(2023– 2026)**

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Abstract

Blood transfusion is a life-saving practice frequently required in traumatized patients, particularly in those with penetrating or blunt trauma, or in those who develop hemorrhagic shock.

This retrospective study describes a population of dogs and cats referred to the Ospedale Veterinario Universitario Didattico (OVUD) of the University of Parma with a diagnosis of trauma. The purpose of this study was to evaluate whether clinical-pathological parameters measured at admission could predict the need for blood transfusion in this population, and whether these predictors differ between the two species.

In the period of time between January 1st 2023 and June 30th 2026 a total of 95 dogs and 106 cats met the inclusion criteria and were included in the study. There was no significant difference between females and males. The median age was 7.6 years for dogs and 4 years for cats, whereas the median weight was 14.7 kg for dogs and 4.31 kg for cats. In both populations, the main type of trauma was motor vehicle accident. The survival rate was 85% in dogs and 83% in cats. Overall, 14 dogs and 17 cats received a blood transfusion during hospitalization.

Among the clinical-pathological variables analyzed, four parameters were confirmed as significant predictors of transfusion requirement in dogs (total protein, albumin, pH, and Shock Index) and four in cats (total protein, albumin, hematocrit, and base excess). Total protein and albumin were the only predictors consistent across both species.

With the exception of Shock Index, which requires a simple calculation, these parameters are already routinely assessed at hospital admission and may support early clinical recognition of trauma patients likely to require transfusion, complementing standard clinical evaluation.

Abstract

La trasfusione di sangue è una pratica salvavita spesso necessaria nei pazienti traumatizzati, in particolare in quelli con un trauma penetrante o contusivo o che sviluppano shock emorragico.

Questo studio retrospettivo descrive una popolazione di cani e gatti riferiti presso l'Ospedale Veterinario Universitario Didattico (OVUD) dell'Università di Parma con diagnosi di trauma. Lo scopo di questo studio era quello di valutare quali parametri clinico-patologici all'ammissione si associno alla necessità di trasfusione in questa popolazione, e se tali associazioni differiscano tra le due specie.

Nel periodo compreso tra il 1° Gennaio 2023 e il 30 Giugno 2026 un totale di 95 cani e 106 gatti ha soddisfatto i criteri di inclusione ed è stato incluso nello studio. Non è stata riscontrata una differenza significativa tra maschi e femmine. L'età mediana era di 7.6 anni nei cani e 4 anni nei gatti, mentre il peso mediano era di 14.7 kg nei cani e 4.31 kg nei gatti. In entrambe le popolazioni, il tipo di trauma più frequente è stato il trauma automobilistico. Il tasso di sopravvivenza è stato dell'85% nei cani e dell'83% nei gatti. Complessivamente, 14 cani e 17 gatti hanno ricevuto una trasfusione di sangue durante il ricovero.

Tra le variabili clinico-patologiche analizzate, quattro parametri sono stati confermati come predittori significativi nel cane (proteine totali, albumina, pH e Shock Index) e quattro nel gatto (proteine totali, albumina, ematocrito e base excess). Le proteine totali e l'albumina sono state gli unici parametri comparsi come predittori in entrambe le specie.

Ad eccezione dello Shock Index, che richiede un semplice calcolo, questi parametri sono già valutati di routine all'ingresso del paziente e possono supportare il riconoscimento clinico precoce della necessità di trasfusione di sangue nei pazienti traumatizzati, uniti alla valutazione clinica standard.

1. Polytrauma patient

Polytrauma is generally defined as the presence of two or more injuries involving multiple body regions or organ systems, at least one of which is potentially life-threatening. [1, 2]

In human medicine, a more standardized definition is provided by the *Berlin definition* [3], which defines polytrauma as the presence of severe injuries (AIS: Abbreviated Injury Scale ≥ 3) affecting at least two body regions, combined with specific physiological parameters: hypotension (systolic blood pressure ≤ 90 mmHg), impaired consciousness (Glasgow Coma Scale ≤ 8), acidosis (base excess ≤ -6.0 mmol/L), coagulopathy (PTT ≥ 40 s or INR ≥ 1.4), or age ≥ 70 years. In the absence of an equivalent scoring system in small animals, this human framework is frequently adopted as a conceptual reference.

Trauma is one of the leading causes of morbidity and mortality in small animal emergency medicine [4] and a common reason for presentation to veterinary emergency services and intensive care units, accounting for approximately 10–30% of ICU admissions. [1]

1.1 Epidemiology, clinical relevance and prognostic of trauma

The most common causes of polytrauma in small animals include road traffic accidents, falls from height, bite wounds, crush injuries, and penetrating trauma. [5, 6]

According to the ACVECC Veterinary Committee on Trauma (VetCOT) registry, which collected information from nearly 10,000 canine and feline trauma patients between 2022 and 2023, the etiology of trauma differs between species: in dogs, traumatic injuries are most frequently associated with bite wounds, vehicular accidents, and lacerations; whereas cats are more commonly affected by blunt trauma of unknown origin, bite-related injuries, and falls from height. [7]

These traumatic events frequently involve multiple organ systems, including musculoskeletal, thoracic, abdominal, neurological, and integumentary structures. [5]

The severity of clinical presentation depends not only on the anatomical extent of injuries, but also on physiological consequences, such as hemorrhage, hypoperfusion, hypoxemia, and systemic inflammation. [4]

In severely injured patients, the inflammatory response may progress to systemic inflammatory response syndrome (*SIRS*), multiple organ dysfunction syndrome (*MODS*), and death if prompt intervention is not undertaken. [2]

For this reason, rapid assessment and stabilization are essential, following a structured approach that prioritizes airway, breathing, circulation, neurological status, and exposure (ABCDE approach). [4]

In a retrospective study of 4,626 canine and feline trauma cases, the authors emphasized that prognosis is determined by a combination of injury-related and non-clinical factors. While the characteristics of the traumatic event, including its mechanism, severity, and anatomical location, play a fundamental role, outcome may also be influenced by owner-related factors – most notably the decision to pursue treatment versus euthanasia for financial, logistical, or other non-medical reasons – which reflect the owner's lifestyle, management strategies, and the nature of the human-animal relationship. [8]

Definitive management of individual injuries is performed only after life-threatening conditions have been stabilized. [5]

2. Evaluation of the traumatized patient

The initial assessment of a polytraumatized patient should begin with a rapid triage evaluation aimed at identifying life-threatening conditions and prioritizing medical interventions. [1]

Triage allows clinicians to rapidly categorize patients according to injury severity and urgency of treatment, facilitating the allocation of available resources and ensuring that the most severely affected patients receive immediate attention. [9]

2.1 Vascular access

In critically ill patients, obtaining vascular access is a priority, particularly when the primary survey reveals abnormalities requiring immediate intervention. Intravenous catheterization is most commonly performed in peripheral veins, such as the cephalic or lateral saphenous vein, allowing the administration of fluids and medications. Central venous catheterization may also be considered when appropriate; however, it is generally contraindicated in patients with suspected coagulopathies or increased intracranial pressure. In pediatric and neonatal patients, very small animals, or patients in which vascular access is difficult to obtain and rapid resuscitation is required, intraosseous catheterization represents an effective, potentially lifesaving alternative. [10]

2.2 Laboratory diagnostics

Blood samples should ideally be collected at the time of intravenous catheter placement to facilitate prompt clinicopathological evaluation. A minimum database typically includes packed cell volume (PCV), total solids (TS), blood urea nitrogen (BUN), blood glucose concentration, and blood smear evaluation. Whenever possible, venous blood gas evaluation, electrolyte measurement, and lactate and creatinine determination should also be obtained. These parameters provide valuable information on the patient's physiological status and help guide early therapeutic decision-making. [10]

In dogs and cats with acute hemorrhage, packed cell volume (PCV) and total solids (TS) should always be interpreted together. Following acute blood loss, PCV may initially remain in the reference interval, or even increase transiently in dogs due to splenic contraction, whereas TS

often decrease earlier because plasma proteins are lost with whole blood. Consequently, a normal PCV does not exclude significant hemorrhage, and serial measurements of PCV, TS and hemoglobin are recommended during patient stabilization to detect ongoing blood loss and evaluate the response to resuscitation. [11]

Blood glucose is routinely assessed because alterations in glucose homeostasis are common during critical illness. Hyperglycemia is frequently observed after acute trauma and may reflect the severity of the underlying disease process. [12] Hypoglycemia, although less frequent, may occur in severely compromised patients, particularly in association with sepsis, severe hepatic dysfunction, or prolonged shock. Early recognition of these alterations is therefore important to identify metabolic alterations and support appropriate therapeutic management. [13]

Blood gas analysis is an essential component of the evaluation of traumatized patients, as it provides information on acid–base status, ventilation, and the metabolic consequences of impaired tissue perfusion. When oxygen delivery is insufficient to meet cellular demand, anaerobic metabolism increases and lactate accumulates, producing metabolic acidosis; evaluation of blood pH, bicarbonate concentration, and base excess therefore reflects the severity of systemic derangements and helps guide therapy. [14]

Within this framework, blood lactate concentration is widely used as an indirect marker of tissue hypoperfusion and oxygen debt: in veterinary critical care, hyperlactatemia is generally defined as a concentration exceeding approximately 2–5 mmol/L, whereas persistent marked increases associated with metabolic acidosis are suggestive of lactic acidosis. In trauma patients, increased lactate concentrations at admission may reflect shock, inadequate tissue perfusion or alterations in oxygen delivery. Furthermore, serial lactate measurements and evaluation of lactate clearance may provide valuable information regarding the effectiveness of resuscitation and the patient's response to therapy. [15]

The clinical relevance and the prognostic value of lactate measurement in traumatized dogs is supported by several studies. Lagutchik et al. [16] found that critically ill animals, including those with major trauma, had significantly higher venous lactate concentrations than healthy dogs, and that non-surviving dogs showed higher lactate values than survivors.

In addition, admission base excess has been shown to be a useful indicator of transfusion requirements in patients with blunt traumatic injuries. A retrospective study of 52 dogs with blunt trauma reported that a base excess threshold of -6.6 mmol/L predicted the need for red blood cell transfusion with a sensitivity of 88% and a specificity of 73%. [17]

According to *Poirier et al.* [18] alterations in acid–base status and markers of tissue perfusion are associated with outcome in traumatized dogs: lower blood pH, bicarbonate concentration, and base excess, together with increased plasma lactate concentrations, have been associated with reduced survival rates, underscoring the prognostic value of blood gas analysis in trauma patients.

Electrolyte assessment is likewise important, as disturbances can have important implications for cardiovascular function, neuromuscular activity, and therapeutic management. [19] Sodium abnormalities reflect alterations in water balance and fluid distribution, and severe or rapidly developing changes may contribute to neurological impairment. Potassium disturbances are particularly relevant in critically ill patients because both hypo and hyperkalemia can affect myocardial excitability and predispose to potentially life-threatening cardiac arrhythmias. Measurement of ionized calcium may also be clinically relevant, particularly in patients with severe trauma or hemorrhage, as alterations in calcium concentration may influence coagulation and cardiovascular function. [14]

Serial creatinine measurement, combined with monitoring of urine output, is useful for monitoring renal function and identifying the early development of acute kidney injury. [19]

When indicated, point-of-care testing should be complemented by a complete blood count, serum biochemistry profile, urinalysis, and coagulation testing. [19]

2.3 Diagnostic imaging

2.3.1 Focused Assessment with Sonography for Trauma (FAST)

Focused Assessment with Sonography for Trauma (FAST) has been widely used in human emergency medicine since the early 1990s as a rapid method for detecting free fluid in trauma patients. [20] In veterinary medicine, its application is more recent and includes abdominal (AFAST) and thoracic (TFAST) examinations in dogs and cats [21]. AFAST is considered an ideal initial screening tool for unstable patients as it can be performed immediately after triage and simultaneously with other diagnostic and therapeutic procedures. [22]

In human medicine, *Nordenholz et al.* [23] demonstrated that FAST provides high sensitivity and specificity for detecting blunt trauma-related injuries, performing comparably to diagnostic peritoneal lavage and computed tomography in identifying free abdominal fluid.

The Abdominal Fluid Score (AFS) is a semi-quantitative scoring system (from 0 to 4) used during AFAST examinations to estimate the amount of free abdominal fluid. The score reflects the number of abdominal ultrasound windows in which free fluid is detected, with higher scores indicating a greater volume of effusion and potentially more severe intra-abdominal hemorrhage. [24] When applied to serial examinations the AFS allows clinicians to rapidly monitor and semi-quantify abdominal effusion in trauma patients. [24]

Four view	Negative	Positive
1 Diaphragmatic-hepatic site	0	1
2 Spleno-renal site	0	1
3 Cysto-colic site	0	1
4 Hepato-renal site	0	1

Table 1: Description of the 4-windows of the A-FAST. [21]

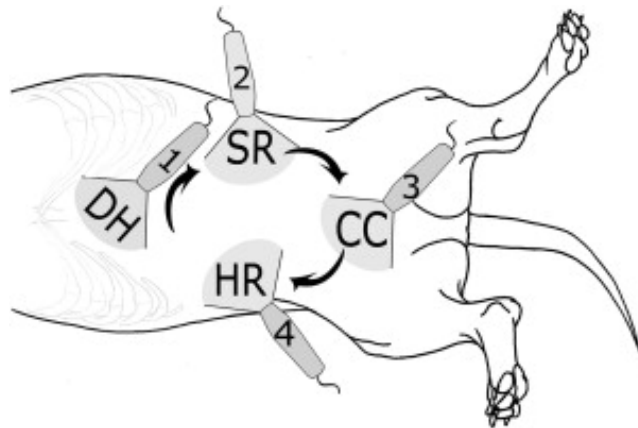


Figure 1: Description of the 4-view of the A-FAST. [21]

The Thoracic Focused Assessment with Sonography for Trauma (TFAST) is a point-of-care ultrasound technique developed to provide a rapid evaluation of the thoracic cavity and to identify life-threatening conditions such as pneumothorax, pleural effusion, and pericardial effusion, particularly in emergency and trauma patients. As with AFAST, it is a rapid, non-invasive, and repeatable examination that can be performed during the initial assessment of critically ill animals. [25]

A study in human medicine has shown that thoracic ultrasonography is more sensitive than supine chest radiography for the detection of pneumothorax, while maintaining a comparable specificity. [25] Thoracic ultrasound has also been described as an extension of the physical examination in emergency and critical care settings, owing to its high sensitivity and specificity in detecting pleural and pericardial effusions.

The TFAST protocol includes five scanning sites: the bilateral chest tube site (CTS), bilateral pericardial sites (PCS), and the diaphragmatic-hepatic (DH) view. The CTS is primarily used to assess for pneumothorax and pulmonary abnormalities, whereas the PCS and DH views facilitate the detection of pleural and pericardial effusions. [21]

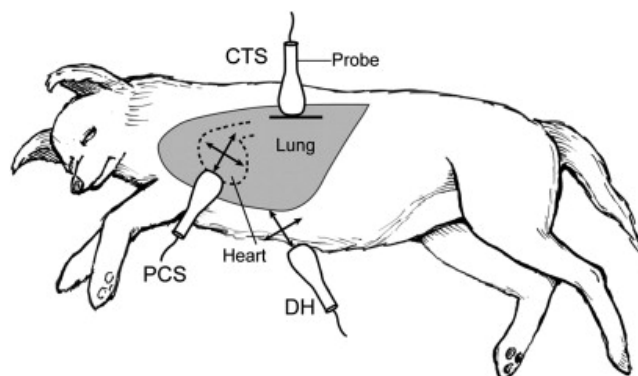


Figure 2: Description of the 5-point T-FAST. [21]

2.3.2 Thoracic radiography

In addition to focused ultrasonography, thoracic radiography remains an essential diagnostic tool in the assessment of traumatic patients. Chest radiographs are particularly valuable for identifying conditions such as pneumothorax, pleural effusion, pulmonary contusions, rib fractures, and diaphragmatic hernias. [10]

In cases of diaphragmatic rupture, radiographic findings may include loss of diaphragmatic continuity, displacement of abdominal organs into the thoracic cavity, and reduced visualization of thoracic structures. [27]

Although radiography is less sensitive than ultrasonography for detecting small volumes of free fluid, it provides important information regarding thoracic injuries. [10]

Additional imaging modalities, such as computed tomography (CT), may also be employed in the evaluation of trauma patients. CT provides a comprehensive assessment of traumatic injuries and is particularly valuable for identifying occult lesions that may be missed during the initial evaluation. However, due to its higher cost, greater resource requirements, and radiation exposure, it is generally reserved for selected patients, particularly those with severe trauma who are hemodynamically stable or have been adequately stabilized. [28]

2.4 Prognostic indicators and scoring systems

To support clinicians during triage, several trauma scoring systems have been developed in veterinary medicine. The most commonly used include the Shock Index (SI), the Animal Trauma Triage Score (ATT), the Acute Patient Physiologic and Laboratory Evaluation (APPLE) score, and the Modified Glasgow Coma Scale (MGCS). [29]

2.4.1 Animal Trauma Triage Score (ATT)

Animal Trauma Triage (ATT) score is one of the most widely used tools for the assessment of canine and feline trauma patients. It evaluates six physiological and anatomical categories (perfusion, cardiac, respiratory, eye/muscle/integument, skeletal, neurological), each assigned a score from 0 to 3, for a maximum total score of 18. Higher ATT scores have been associated with increased injury severity and poorer clinical outcomes, making this scoring system a valuable aid in both triage and prognostic assessment. [30, 31]

Perfusion	
MM pink/moist, CRT 2 sec, T $\geq$ 100F, strong or bounding femoral pulse quality	0
MM hyperemic or pale pink, MM tacky, T $\geq$ 100F, CRT 0-2 sec, fair femoral pulses	1
MM very pale pink & tacky, CRT 2-3 sec, T < 100F, detectable but poor pulse	2
MM gray/blue/white, CRT > 3 sec, T < 100F, non-palpable femoral pulses	3
Cardiac	
HR canine: 60-140 bpm; feline: 120-200 bpm, normal sinus rhythm	0
HR canine: 140-180 bpm; feline: 200-260 bpm, NSR or VPC < 20/min	1
HR canine: >180 bpm; feline: >260 bpm, consistent arrhythmia	2
HR canine: <60 bpm; feline: $\leq$ 120 bpm, erratic arrhythmia	3
Respiratory	
Regular respiratory rate with no stridor, no abdominal component to resp	0
Mild increased respiratory rate and effort, $\pm$ abdominal component, mild upper airway sounds	1
Mod increased respiratory rate and effort, some abdominal component, elbow abduct, moderate increased upper airway	2
Marked respiratory effort or gasping/ agonal resp, little/ no air passage	3

Eye/ Muscle/ Integument	
Abrasion/ laceration – none or partial thickness. Eye: no fluorescein uptake.	0
Abrasion/ laceration – full thickness, no deep tissue involved. Eye – corneal lac not perforation	1
Abrasion/ laceration – full thickness, deep tissue involved, art/ nerve/ muscle intact. Eye – corneal perforation, punctured globe or proptosis.	2
Penetration of abdomen/thorax. Abrasion/laceration full thickness, deep tissue involved, artery/nerve/muscle compromised	3
Skeletal	
WT bearing 3 or 4 limbs. No palpable fx/joint laxity	0
Closed limb fx/rib fx or any mandibular fx. Single joint laxity/lux (including SI). Pelvic fx with unilateral intact SI-ilium-acetabulum. Single limb open/closed fx at or below carpus/tarsus	1
Multiple grade 1 conditions, single long bone open fx above carpus/tarsus with cortical bone preserved. Non-mandibular skull fx	2
Vertebral body fx/luxation except coccygeal, multiple long bone open fx above tarsus/carpus, single long bone open fx above tarsus/carpus with loss of cortical bone	3
Neurologic	
Central: consciousness: alert to dull, interest in surrounding. Periph: normal spinal reflexes; purposeful movement and nociception in all limbs	0
Central: dull/depressed/withdrawn. Periph: abnormal spinal reflexes with purposeful movement and nociception intact in all 4 limbs.	1
Central: unconscious, responds to noxious stimuli. Periph: absent purposeful movement with intact nociception in 2 or more limbs or nociception absent in 1 limb, decr anal or tail tone.	2
Central: non responsive to all stimuli, refractory seizures. Periph: absent nociception in two or more limbs, absent tail or perianal nociception	3

Table 2: The Animal Trauma Triage Scoring System. [30]

A retrospective study of 37 dogs and cats with gunshot injuries investigated the utility of the Animal Trauma Triage (ATT) score as a prognostic indicator. Higher ATT scores at admission were associated with a decreased likelihood of survival to discharge, a greater need for surgical intervention and blood transfusion, and longer hospitalization times. [32]

2.4.2 Modified Glasgow Coma Scale (MGCS)

The Modified Glasgow Coma Scale (MGCS) is a neurological scoring system adapted from human medicine to assess the severity of traumatic brain injury in veterinary patients. It evaluates three categories - motor activity, brainstem reflexes, and level of consciousness - generating a score from 3 to 18, with lower scores indicating more severe neurological dysfunction. [33]

The prognostic utility of the Modified Glasgow Coma Scale (MGCS) has been further investigated in large multicenter study conducted by the Veterinary Committee on Trauma (VetCOT). This study, involving 711 injured cats, evaluated the performance of both the Animal Trauma Triage (ATT) score and the MGCS as predictors of survival: lower MGCS scores were significantly associated with increased mortality, confirming the usefulness of neurological assessment in feline trauma patients; however, the ATT score demonstrated superior overall predictive ability. [30]

Similarly, *Lapsley et al.* [31] assessed the prognostic performance of the ATT score and MGCS in a large population of traumatized dogs. Both scoring systems were significantly associated with survival outcome, with lower MGCS scores correlating with an increased risk of death. The study supported the use of the MGCS as a valuable prognostic tool, particularly in patients with neurological injury, while also confirming the strong predictive value of the ATT score in the trauma population.

2.4.3 Acute Patient Physiologic and Laboratory Evaluation (APPLE) score

One of the most comprehensive and validated illness-severity scoring systems currently available for dogs and cats is the Acute Patient Physiologic and Laboratory Evaluation (APPLE) score. [34, 35] It was derived from physiological and laboratory data collected within the first 24 hours after hospital admission; significant predictors of mortality were then included into multivariable logistic regression models to identify the strongest associations with outcome. [34]

The final models were reduced to either 10 variables (APPLEfull) or 5 variables (APPLEfast) in dogs, and 8 variables or 5 variables, respectively, in cats. Each variable is assigned a weighted score, for a maximum total score of 80 for APPLEfull and 50 for APPLEfast. Both scoring systems demonstrated strong predictive performance. [34]

Subsequent studies have evaluated the prognostic performance of the APPLE scoring systems across a variety of critical illnesses, particularly in dogs with systemic inflammatory response syndrome (SIRS) and sepsis. In dogs with SIRS, the APPLEfast score was identified as an independent predictor of survival, supporting its usefulness for illness severity assessment in critically ill patients. [36]

In canine trauma patients, APPLE scores have been investigated as prognostic indicators of outcome. In a population of dogs with moderate-to-severe trauma, higher APPLE scores were associated with increased mortality risk, and an APPLE score threshold of 31 showed good discrimination between survivors and non-survivors, with high sensitivity and specificity for predicting non-survival. [37]

Apple_{full} Score - canine

			0 points			
			Creatinine (mg/dL)	1	8	9
			≤ 0.62	.63 - 1.35	1.36 -	> 2.26
			wbc x 10⁶/mL	2	3	
			< 5.1	5.1 - 8.5	8.6 - 18	> 18
6	7	9	albumin (mg/dL)	2		
< 2.6	2.6 - 3.0	3.1 - 3.2	3.3 - 3.5	> 3.5		
10	4	1	SpO₂ (%)			
< 90	90 - 94	95 - 97	98-100			
			total bilirubin (mg/dL)	6	4	3
			< 0.23	0.4 - 0.46	0.47 -	> 0.93
			mentation score	5	7	8
			0	1	2	3
			respiratory rate (BPM)	3	5	6
			< 25	25 - 36	37 - 48	49 - 60
			age (years)	6	8	7
			0-2	3 - 5	6 - 8	> 8
3	4		fluid score			
2	1		0			
			lactate (mmol/L)	2	3	6
			0-1.9	2.0 - 7.9	8.0 - 11.0	> 11

Table 3: Canine Acute Patient Physiologic and Laboratory Evaluation (APPLE_{full}) score. [34]

				0 points					
7 < 84	8 84 - 102	9 103 -	10 165 -	glucose (mg/dL) > 273					
				8 < 2.6	7 2.6 - 3.0	6 3.1 - 3.2	albumin (g/dL) 3.3 - 3.5		2 > 3.5
				lactate (mmol/L) < 2		4 2 - 8	8 8 - 10	12 > 10	
5 < 151	6 151 -	3 201 -	platelet count (x10 ³ /mL) 261 - 420		1 > 420				
				mentation score 0		4 1	6 2	7 4	14 4

			0 points					
			Mentation score	4	7	8	9	
			0	1	2	3	4	
6 < 36.1 [97]	4 36.1 [97] - 37.0 [98.6]	3 37.1 [98.7] - 38.5 [101.4]	Temperature (C[F])	1 > 39.4 [102.9]				
			38.6 [101.5] - 39.4 [102.9]					
	9 < 61	4 61 - 100	MAP (mmHG)	1 > 140				
			Lactate (mmol/L)	5 2.0 - 4.0	6 4.1 - 7.0	9 > 7.0		
			PCV (%)	11 11 - 20	16 21 - 30	14 31 - 40	13 41 - 45	17 > 45
	11 < 14.9	7 14.9 - 21.3	BUN (mg/dL)	12 21.4 - 24.9	7 25.0 - 32.5	6 32.6 - 69.8		
			21.4 - 24.9	25.0 - 32.5	32.6 - 69.8	> 69.8		
12 < 111	9 111 - 115	11 116 - 118	Chloride (mEq/L)	11 119 - 122	7 123 - 125			
			119 - 122	123 - 125	> 125			
			Body cavity fluid score	3 1	6 2			
			0					

				0 points								
				Mentation score	5	6	7	10				
				0	1	2	3	4				
6 < 35.6 [96]	5 35.6 [96] - 36.0 [96.8]	4 36.1 [97] - 37.0 [98.6]	37.1 [98.7] - 38.5 [101.4]	38.6 [101.5] - 39.5 [103.1]	> 39.5 [103.1]							
				11 < 61	7 61 - 100				MAP (mmHg) 101 - 140	1 > 140		
								lactate (mmol/L) 0 - 1.9	6 2.0 - 4.0	9 4.1 - 7.0	10 > 7.0	
								PCV (%) < 16	12 16 - 25	10 26 - 35	9 36 - 45	13 > 45

2.4.4 Shock index (SI)

The Shock Index (SI), defined as the ratio between heart rate (HR) and systolic arterial blood pressure (SBP), was originally developed as a simple bedside tool to quantify the severity of circulatory shock at presentation to the emergency department and to monitor response to therapy in human patients. [38] The index was first validated in a porcine model of hemorrhagic shock, in which it correlates inversely with cardiac index, stroke volume, mean arterial pressure, left ventricular stroke work, oxygen delivery, and mixed venous oxygen saturation. [39]

Subsequent studies in human emergency and trauma patients have demonstrated the clinical usefulness of the SI, particularly in the early assessment of traumatic injuries. It has been proposed as a surrogate marker of left ventricular stroke work and overall cardiac function, reflecting the cardiovascular response to hypovolemia and shock. In human medicine, SI values greater than 0.9 are generally associated with severe illness and the need for urgent intervention and close monitoring. [39]

One of the main advantages of the Shock Index is its ability to detect occult hypoperfusion, even in patients with apparently normal vital parameters. Its simplicity, rapid calculation, and low cost make it a practical tool for the early identification of patients at risk of clinical deterioration. Despite its established use in human medicine, the Shock Index has not yet been extensively evaluated in veterinary patients, including those with clinical signs of shock, although its potential applicability in small animal emergency and critical care appears promising. [38, 39]

In a retrospective study of dogs with vehicular trauma, the Shock Index (SI) was assessed as a potential prognostic indicator of outcome. Dogs with higher SI values at presentation were more likely to have a poor outcome than survivors. SI was significantly associated with mortality, suggesting that an increased heart rate relative to systolic blood pressure reflects more severe circulatory compromise. [40]

In an experimental canine study, the Shock Index increased proportionally with blood loss and correlated negatively with cardiac output, supporting its physiological relevance as a marker of hypovolemia. However, despite its sensitivity to changes in intravascular volume, SI did not reliably normalize following resuscitation, indicating that it should not be used as a standalone endpoint for guiding fluid therapy. [41]

3. Transfusion medicine in dogs and cats

Blood transfusion is a life-saving medical procedure widely used in veterinary medicine for the management of a variety of conditions, including acute hemorrhage, severe anemia, and coagulopathies. In both dogs and cats, transfusion therapy plays a fundamental role in stabilizing patients and improving clinical outcomes when other treatments are insufficient or act too slowly. [42, 43]

The practice of blood transfusion has a long and remarkable history. The first documented transfusion was performed in 1665 by Richard Lower, who successfully transferred blood from one dog to another; since then, this procedure has evolved into a fundamental life-saving intervention in both human and veterinary medicine. [44]

Over the past sixty years, veterinary transfusion medicine has advanced considerably. At the same time, the expansion of scientific knowledge and the increasing availability of blood products have made transfusion therapy more complex: a growing understanding of blood group diversity, together with the need for careful donor screening, blood typing, and crossmatching has made the selection of the most appropriate donor unit for each patient increasingly demanding. [43]

3.1 Blood Banking

Veterinary blood banking is a fundamental component of transfusion medicine, ensuring appropriate donor selection, blood typing, infectious disease screening and the collection, processing, storage and distribution of blood products. This supports a more targeted use of transfusion products, allowing clinicians to select the component most suitable for each patient while reducing the risk of adverse reactions. [45]

Veterinary practices may adopt different approaches to blood banking depending on their caseload, available resources, and financial considerations. Blood products may be obtained from commercial blood banks, collected from in-house donor colonies, or sourced from staff-owned or client-owned donor animals and in many cases, a combination of these strategies is used. Nevertheless, in emergency settings or when commercial blood products are unavailable or cost-prohibitive, immediate collection from in-house donor animals may represent the only option. [46]

3.2 Blood donor selection

Appropriate donor selection is essential for maintaining the quality and safety of blood products while safeguarding donor welfare. The main selection criteria for canine and feline blood donors are presented in Table 7. [45]

Parameter	Canine	Feline
General health	Clinically healthy	Clinically healthy
Weight	>25 kg	> 4.5 kg
Age	1-8 years	1-8 years
Reproductive status	Preferably neutered	Preferably neutered
Hct	≥ 35%	≥ 35%
Infectious disease screening	Vaccinated, no infectious disease history	Vaccinated, FeLV/FIV/hemoplasma negative
Blood typing	DEA 1 - preferred	Blood type determined

Table 7: Criteria for selecting blood donors. Adapted from [45].

In addition, all potential blood donors should undergo screening for transfusion-transmissible infectious diseases (TTIDs). Screening protocols should be based on the geographical distribution of infectious agents, the donor's travel history, lifestyle, and individual risk factors. Routine testing reduces the risk of pathogen transmission through blood transfusion and contributes to maintaining a safe and reliable blood supply. [43, 47]

Species	Routine screening	Additional screening according to geographic area or risk factors
Dog	Anaplasma spp., Babesia spp., Bartonella spp., Ehrlichia spp., Mycoplasma haemocanis	Leishmania infantum, Brucella canis, Typanosoma cruzi
Cat	FeLV, FIV, Feline haemoplasmas	Bartonella henselae, Cytauxzoon felis

Table 8: Recommended screening tests for canine and feline blood donors. Adapted from [47].

Health screening and testing for transfusion-transmissible infectious diseases should be performed at least annually in blood donors and more frequently in animals that become ill, are at increased risk of vector exposure, or live in areas where blood-borne pathogens are endemic. Routine screening before every blood donation is generally not performed in veterinary medicine because of the costs involved and the time required to obtain laboratory results. [19, 47]

Total blood volume is generally estimated at approximately 80–90 mL/kg in dogs and 50–60 mL/kg in cats. Healthy donors can safely donate around 10% of their total blood volume without clinically relevant adverse effects. Collection of up to 15–20% of total blood volume is generally considered acceptable in clinically healthy donors with a normal PCV, although transient hypovolaemia may occur. Volumes exceeding 20% are not recommended, as they may lead to clinically significant cardiovascular compromise and excessive reduction in PCV. [47, 48] In practical terms, this corresponds to approximately 450–500 mL of whole blood from a 25–30 kg dog and about 40–60 mL from a 4–5 kg cat. It is important to consider that blood volume is based on lean body weight. [48]

Erythrocyte regeneration typically occurs within days to weeks, allowing repeat donations at intervals of approximately 4–6 weeks. However, many blood banking protocols limit donations to 4–5 times per year to prevent overstimulation of erythropoiesis and potential depletion of iron stores. [48]

3.3 Indications for transfusion in the polytraumatized patient

3.3.1 Acute Hemorrhage

Hemorrhage is one of the leading causes of preventable death in traumatized veterinary patients, particularly in dogs with blunt or penetrating trauma. Acute blood loss may rapidly result in hypovolemia, decreased oxygen-carrying capacity, and progression to hemorrhagic shock, making early recognition of compromised perfusion essential for identifying patients requiring transfusion support. [49]

Initial assessment should include cardiovascular parameters such as heart rate (HR) and systolic blood pressure (BP); however, these variables may remain within normal reference ranges during the early stages of hemorrhage due to compensatory mechanisms. Therefore, serial evaluation

of additional perfusion markers is recommended. [49] Beyond reflecting the shift toward anaerobic metabolism during inadequate tissue oxygen delivery, blood lactate concentration also carries independent prognostic value: in a large retrospective study of dogs and cats presenting to an emergency room, elevated lactate was associated with increased in-hospital mortality, and animals with concurrent lactic acidosis showed a significantly higher mortality risk than those with hyperlactatemia and a normal acid–base status. [50]

Aggressive crystalloid administration was historically the standard approach to trauma resuscitation, aimed at rapidly restoring intravascular volume and maintaining organ perfusion. However, concerns have emerged regarding excessive crystalloid infusion, as high-volume fluid therapy may promote hemodilution, worsen coagulopathy, and contribute to tissue edema, particularly in patients with ongoing hemorrhage. [51]

In patients with severe hemorrhage, resuscitation strategies have progressively shifted toward a Damage Control Resuscitation (DCR) approach, which aims to support tissue perfusion while minimizing disruption of hemostasis and limiting complications associated with uncontrolled bleeding. Unlike traditional aggressive fluid resuscitation, DCR emphasizes early hemorrhage control, restricted crystalloid administration, and balanced transfusion of blood products. [51] Within this framework, blood transfusion is no longer considered a rescue therapy reserved for severe anemia, but an essential component of early resuscitation in actively bleeding patients. [49]

Blood products are used in hemorrhagic patients to restore oxygen-carrying capacity and support hemostasis by replacing cellular and coagulation components lost during bleeding. This is particularly relevant in trauma patients, in whom coagulopathy may contribute to ongoing hemorrhage and requires a multimodal resuscitation strategy. [11,49]

The clinical relevance of transfusion therapy in canine trauma patients has been described by *Lynch et al.* [52] who evaluated transfusion practices in 125 dogs hospitalized following traumatic injury. Forty-five dogs (36%) received a blood transfusion, with packed red blood cells representing the most frequently administered blood product. The main indications for transfusion included perioperative hemodynamic support, treatment of hemorrhagic shock, and

progressive anemia. Notably, admission PCV and total solids concentration were found to be specific but relatively insensitive predictors of subsequent transfusion.

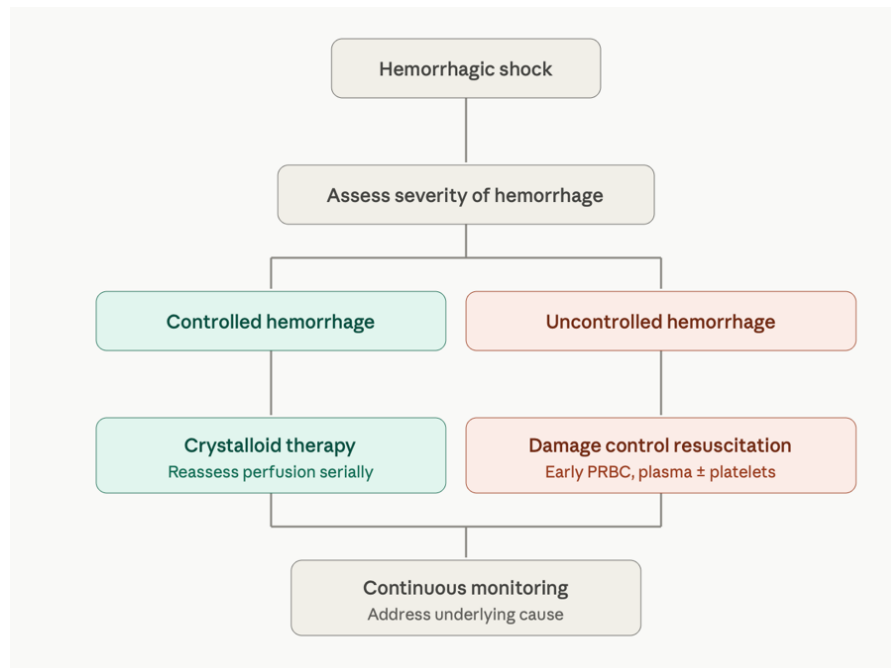


Figure 3: Simplified management scheme for acute hemorrhage, adapted from [19].

3.3.2 Massive transfusion

Massive transfusion is required in veterinary patients with severe, uncontrolled hemorrhage and hemorrhagic shock to restore circulating volume, oxygen delivery, and hemostatic function. It is generally defined as the administration of blood products equivalent to the patient's blood volume within 24 hours or a substantial proportion of it within a shorter period. The decision to initiate massive transfusion should be based on evidence of active hemorrhage and clinical instability. [53]

The TASH score was originally developed and validated in a large cohort of human trauma patients as a rapid, easy-to-apply tool for estimating the likelihood of massive transfusion, with the aim of directing early clinical attention toward hemorrhage control and coagulation management. [54] In veterinary medicine, this human-based score has more recently been applied to dogs with trauma. In a retrospective study evaluating the Trauma-Associated Severe Hemorrhage (TASH) score in dogs, transfused patients had significantly higher scores than non-transfused controls; among individual components, a more negative base excess and the

presence of abdominal fluid detected by ultrasonography were associated with increased transfusion requirements, highlighting the potential value of combining perfusion markers with imaging findings during initial trauma assessment. [55]

Massive transfusion aims to provide rapid and balanced replacement of blood components, with the administration of packed red blood cells together with plasma, and when available platelet products, allowing simultaneous correction of oxygen-carrying capacity and coagulation impairment. In veterinary patients, transfusion strategies must be adapted to the severity of hemorrhage, clinical response, and availability of blood products, as standardized massive transfusion protocols are not as well established as in human trauma medicine. Continuous monitoring is required to identify and manage complications such as hypothermia, coagulopathy, and citrate-associated hypocalcemia. [4, 53]

In human medicine, the PROPPR trial directly compared two transfusion ratios — 1:1:1 versus 1:1:2 of plasma, platelets, and red blood cells — in patients with severe trauma and major bleeding. Although overall mortality at 24 hours and at 30 days did not differ significantly between the two protocols, the balanced 1:1:1 ratio was associated with a higher rate of hemostasis and fewer early deaths from exsanguination, without additional safety concerns despite the greater volume of plasma and platelets administered. [56]

3.3.3 Trauma-induced coagulopathy

In patients with severe trauma and ongoing hemorrhage, persistent bleeding may be associated with trauma-induced coagulopathy (TIC), an endogenous disturbance of hemostasis that develops after severe traumatic injury and hemorrhagic shock. It is characterized by early and dynamic alterations in coagulation pathways, resulting from the combined effects of tissue injury, systemic hypoperfusion, endothelial disturbance, and dysregulated fibrinolysis, which may contribute to persistent bleeding and adverse outcomes. [57]

In veterinary medicine, evidence regarding TIC remains limited. In a prospective study evaluating 18 dogs and 19 cats with blunt trauma, *Gottlieb et al.* [58] identified overt acute traumatic coagulopathy in only one dog and one cat. However, in dogs, increasing injury severity was significantly associated with prolonged PT and aPTT and reduced clot strength, suggesting that coagulation abnormalities become more evident in severely injured patients.

3.4 Blood products

Modern transfusion medicine has progressively shifted from the administration of whole blood toward component therapy, in which blood is separated into specific products that can be administered according to the individual requirements of the patient. This approach allows more efficient use of donated blood resources. However, the use of multiple blood components may increase the risk of dilutional effects and metabolic complications, making an individualized transfusion strategy essential. [59]

3.4.1 Packed red blood cell (PRBC)

Packed red blood cells (PRBCs) are primarily indicated for the treatment of clinically significant anemia and aim to restore red blood cell mass and oxygen-carrying capacity. Clinical manifestations may include pale mucous membranes, weakness, exercise intolerance, tachypnea, tachycardia, and, in severe cases, hypotension. Transfusion decisions should be based on the severity of anemia, clinical signs, cardiovascular status, and evidence of inadequate oxygen delivery rather than on hematocrit values alone. Although specific transfusion thresholds are not well established, an HCT of approximately 15–18% is commonly used as a guideline for considering red blood cell transfusion, while higher values may be required in patients with compromised cardiovascular function. [43]

Prospective clinical evidence also supports the physiological benefits of PRBC transfusion in anemic dogs. In a study of 26 dogs, transfusion resulted in significant increases in hematocrit and hemoglobin together with improvements in perfusion and acid–base variables, including reductions in heart rate, respiratory rate, lactate concentration, and base deficit. Moreover, higher pre-transfusion lactate concentrations were associated with increased mortality, suggesting that lactate may represent a useful prognostic marker in severely anemic patients. [60]

3.4.2 Fresh whole blood

Fresh whole blood contains both cellular and plasma components - including erythrocytes, coagulation factors, and platelets - making it a valuable option in patients with acute massive blood loss. Although, the separation of whole blood into individual components allows more targeted replacement of specific deficiencies and improves the utilization of donated blood products, interest in whole blood has recently grown in trauma patients with severe hemorrhage, as it may simultaneously address deficits in oxygen-carrying capacity and hemostasis associated with major blood loss. [51, 59]

3.4.3 Plasma products

Plasma is the component of blood obtained after separation from whole blood. It contains coagulation factors, albumin, immunoglobulins, anticoagulants, and other plasma proteins. Depending on processing and storage, plasma products are classified as fresh frozen plasma (FFP), which preserves both stable and labile coagulation factors, or frozen plasma (FP), in which labile coagulation factors are progressively reduced while stable coagulation factors remain available. [43, 59]

Plasma products are primarily indicated for the management of coagulation disorders through replacement of deficient clotting factors. Fresh frozen plasma is considered the treatment of choice for patients with documented congenital or acquired coagulation factor deficiencies and active hemorrhage. [43, 59] However, prophylactic plasma administration in non-bleeding patients with prolonged coagulation times remains controversial: evidence from human medicine suggests that conventional coagulation tests, including PT and aPTT, have a limited ability to predict bleeding risk, and similar concerns have been raised regarding their interpretation in veterinary patients. [59, 61, 62]

Fresh frozen plasma contains all coagulation factors, including the labile factors V and VIII, together with fibrinogen, albumin, fibronectin, α_2 -macroglobulin, and naturally occurring anticoagulants. Frozen plasma, obtained either by freezing plasma more than 8 hours after collection or after prolonged storage of FFP, retains most stable coagulation factors but has reduced activity of labile factors. [43]

Cryoprecipitate is produced from fresh frozen plasma by controlled thawing and contains concentrated amounts of fibrinogen, factor VIII, and von Willebrand factor, making it the preferred product for the treatment of hemophilia A, von Willebrand disease, and hypofibrinogenemia. Conversely, cryoprecipitate-poor plasma retains adequate concentrations of vitamin K-dependent clotting factors (II, VII, IX, and X) and may be used in the management of anticoagulant rodenticide intoxication. [43, 59]

3.4.4 Platelet products

Platelet transfusions are primarily indicated for the management of severe thrombocytopenia or platelet dysfunction associated with clinically significant bleeding, as platelets are essential components of primary hemostasis and their impairment may contribute to inadequate clot formation and persistent hemorrhage. [63]

Clinical evidence regarding platelet transfusion in veterinary patients remains limited. *Davidow et al.* [64] evaluated the feasibility and safety of fresh platelet concentrates and lyophilized platelets in 37 thrombocytopenic dogs presenting with clinical signs of hemorrhage. Both products were associated with a low rate of transfusion reactions, and no significant differences were observed regarding clinical outcomes, need for additional transfusions, or survival. Although lyophilized platelets represent a promising alternative due to their storage advantages, further studies are required to determine their efficacy and post-transfusion platelet survival.

In a retrospective study evaluating 86 thrombocytopenic dogs, of whom 43 received cryopreserved platelet concentrate transfusion and 43 served as untransfused controls, treated dogs showed a significant increase in platelet count after administration and the treatment was well tolerated, with no acute transfusion reactions reported. However, cryopreserved platelet concentrates were not associated with improved clinical bleeding control or survival compared with non-transfused thrombocytopenic dogs. [65]

Despite these advances, platelet transfusion remains less commonly performed in veterinary medicine compared to red blood cell or plasma transfusion, mainly because of limited availability of platelet products, short storage duration, and the logistical challenges associated with their preparation and administration. [59, 63]

3.4.5 Albumin products

Albumin is the main plasma protein responsible for maintaining colloid osmotic pressure and contributes to intravascular volume regulation. Although plasma contains albumin, large volumes are required to achieve clinically relevant increases in serum albumin concentration. Concentrated albumin products, including human serum albumin and canine-specific albumin, have been investigated in critically ill veterinary patients; however, their clinical benefits remain controversial and their role in trauma patients is limited compared with blood products aimed at restoring oxygen delivery and hemostasis. [43, 59]

Product	Main content	Primary indication
PRBC	Concentrated erythrocytes	Clinically significant anemia, restore oxygen-carrying capacity
Fresh whole blood	Erythrocytes + coagulation factors + platelets	Acute massive hemorrhage, combined oxygenation/hemostasis deficit
Fresh frozen plasma	All factors, incl. labile V and VIII, fibrinogen, albumin	Active hemorrhage with documented/suspected coagulation factor deficiency
Frozen plasma	Stable factors preserved, labile factors reduced	Vitamin K-dependent factor deficiency (e.g. rodenticide intoxication)
Cryoprecipitate	Concentrated fibrinogen, factor VIII, vWF	Hemophilia A, von Willebrand disease, hypofibrinogenemia
Cryo-poor plasma	Vitamin K-dependent factors (II, VII, IX, X)	Anticoagulant rodenticide intoxication
Platelet products	Fresh, cryopreserved, or lyophilized platelets	Severe thrombocytopenia/thrombopathia with active bleeding
Albumin products	Concentrated albumin (human or canine-specific)	Oncotic support; role in trauma limited/controversial

Table 9: Summary of blood products used in veterinary transfusion medicine adapted from [42].

4. Blood groups and transfusion compatibility

Knowledge of the blood group systems is essential in transfusion medicine, as incompatibilities between donor and recipient may result in alloimmunization and hemolytic transfusion reactions.

4.1 Canine blood group systems

Blood group antigens have been recognized in dogs for more than a century, with the first erythrocyte antigens described in the early 1900s and blood group systems characterized from the 1940s onward. To date, 13 canine blood group systems have been described, of which five DEA types (DEA 1, 3, 4, 5 and 7) are recognized, although only a limited number have traditionally been available for routine blood typing. The conventional canine blood group classification is based on the Dog Erythrocyte Antigen (DEA) system. [43]

More recently, additional blood groups such as Dal and Kai 1/Kai 2 have been identified. [42]

Among canine blood groups, DEA 1 is considered the most clinically significant due to its high immunogenicity. Historically, the DEA 1 system was described as including different phenotypes, such as DEA 1.1, DEA 1.2 and DEA 1.3, based on differences in antigen expression. However, more recent approaches have simplified this classification by considering dogs as either DEA 1-positive or DEA 1-negative, with variable levels of antigen expression among positive individuals. [42]

Unlike cats, dogs do not naturally possess alloantibodies against the DEA 1 antigen. Therefore, transfusion of DEA 1-positive blood to a DEA 1-negative recipient during the first exposure generally does not result in an immediate hemolytic reaction, but it can induce alloimmunization. If the sensitized recipient is subsequently transfused with DEA 1-positive blood, a severe acute hemolytic transfusion reaction may occur due to the production of anti-DEA 1 antibodies. For this reason, DEA 1 typing represents a fundamental component of canine transfusion practice. [43]

Other canine blood groups include DEA 3, DEA 4, DEA 5 and DEA 7. DEA 4 is highly prevalent in the canine population, being expressed in approximately 98% of dogs, and has historically been associated with the concept of the universal donor. In contrast, naturally occurring alloantibodies

against DEA 3, DEA 5 and DEA 7 have been described, and incompatibilities involving these antigens are primarily associated with delayed hemolytic transfusion reactions characterized by shortened survival of transfused erythrocytes rather than acute hemolysis, although their clinical relevance remains debated. Consequently, these blood groups are considered particularly relevant in patients requiring repeated transfusions, such as dogs with non-regenerative anaemia, although routine typing for DEA 3, DEA 4, DEA 5 and DEA 7 remains largely limited to specialized reference laboratories. [66]

The Dal antigen was first described by *Blais et al.* in 2007 [67] following the identification of anti-Dal alloantibodies in a previously transfused Dalmatian. The incompatibility observed in this patient could not be attributed to any known DEA antigen, leading to the recognition of Dal as a novel canine red blood cell antigen. Anti-Dal antibodies appear to develop following transfusion sensitization rather than being naturally present.

The Dal antigen is highly prevalent in most dogs but is absent in certain breeds, particularly Dalmatians and Doberman Pinschers. [42] A large-scale study evaluating over 1,100 dogs across North America further characterized the prevalence of the Dal blood group, confirming autosomal dominant transmission of the Dal-positive phenotype. Notably, the prevalence of Dal-negative dogs varied substantially by breed, reaching over 40% in Doberman Pinschers and over 50% in Shih Tzus, compared to under 3% among mixed-breed dogs and blood donors overall. These findings indicate a considerably elevated risk of sensitization following transfusion with common Dal-positive blood in predisposed breeds, supporting the recommendation for extended Dal typing in Dalmatians, Doberman Pinschers, and Shih Tzus, particularly when incompatibility problems arise after initial transfusions. [68]

More recently, the Kai blood group system (Kai 1 and Kai 2) has been described as an additional canine erythrocyte antigen system. Most dogs are Kai 1-positive/Kai 2-negative, while alternative phenotypes are less frequent. Although naturally occurring anti-Kai alloantibodies have not been identified, antibodies against Kai antigens have been detected in previously transfused dogs; however, the clinical significance of this system in transfusion medicine remains incompletely understood. [69]

4.2 Feline blood group systems

The feline AB blood group system was first characterized by *Auer and Bell* in 1981 [70] who investigated both the genetic and serological features of red blood cell antigens. In a survey of nearly 1,900 cats from Brisbane, Australia, the majority of individuals were classified as type A, with a smaller proportion expressing type B, and a rare third phenotype — type AB — identified at low frequency. Preliminary genetic analysis indicated that the A allele behaves as dominant over B in most cases.

Naturally occurring alloantibodies in cats show a corresponding asymmetry between blood types. Type B cats typically possess high-titer anti-A alloantibodies, whereas type A cats generally exhibit only low-titer, and often absent, alloantibodies against type B erythrocytes. Type AB cats, in contrast, lack both anti-A and anti-B alloantibodies entirely. Notably, these alloantibodies are not present at birth but develop within the first few months of life, following the physiological decline of maternally derived colostral antibodies. [66]

Feline neonatal isoerythrolysis (FNI) is an immune-mediated hemolytic disease that occurs when a type B queen is mated with a type A tom, producing type A or AB kittens. Because type B queens possess high-titer anti-A alloantibodies, these are transferred to the kittens through colostrum shortly after birth, leading to destruction of their erythrocytes. Severity varies from peracute death to milder anemia, and matings between two type B cats carry no such risk, since all resulting kittens are type B. [71]

As a consequence of this naturally occurring alloimmunization, unlike in dogs, which require prior sensitization to develop a hemolytic reaction, cats can react severely to their first transfusion of mismatched blood. This risk has been quantified in a specific population of cats from Sydney, where an estimated 46% of random, untyped transfusions would result in an incompatible match, with approximately half of these considered potentially life-threatening. [72, 73]

In addition to the AB blood group system, an additional feline red cell antigen, designated Mik, was identified by Weinstein et al. in 2007, [74] during extensive compatibility testing performed on a colony of feline blood donors. Despite confirmed AB compatibility between donor and recipient cats, plasma from a subset of donors produced incompatible crossmatch results with AB-matched erythrocytes, indicating the presence of a naturally occurring alloantibody directed

against a previously unrecognized red cell antigen. The clinical relevance of this finding was demonstrated in a feline renal transplant recipient that developed an acute hemolytic reaction following transplantation from an AB-compatible donor. The recipient was subsequently found to lack the Mik antigen and to possess naturally occurring anti- Mik alloantibodies, while the donor was Mik-positive, despite full AB compatibility between the two cats. This case demonstrated that AB matching alone does not guarantee transfusion compatibility in cats, as naturally occurring alloantibodies directed against non-AB antigens, such as Mik, may also be present.

Following the identification of Mik, subsequent research has revealed that non-AB incompatibilities in cats are more common than previously recognized. A study that screened 258 type A cats for naturally occurring alloantibodies against unknown antigens estimated that at least 7% of type A cats carry such alloantibodies, and identified five previously undescribed feline erythrocyte antigens. Two of these, designated FEA 1 and FEA 5, were highly prevalent within the tested population, and cats lacking FEA 1 showed a markedly increased risk of harboring naturally occurring alloantibodies. Based on its prevalence and pattern of association, the authors proposed that FEA 1 may correspond to the previously described Mik antigen. [75]

A systematic review evaluating 28 studies on feline blood type distribution grouped cat breeds according to four broad geographic and phylogenetic origins: Asian, American, European, and Oceanian. Across all groups, type A remained the predominant blood type, although its prevalence differed somewhat by region, ranging from 72% in Oceanian breeds to 86% in Asian breeds. Type B showed a more marked geographic pattern, being considerably more common in European and Oceanian breeds compared with Asian and American breeds. Type AB remained uncommon across all regions, with the lowest prevalence observed in Oceanian breeds. The authors suggested that these regional patterns may partly reflect historical trade and colonization routes connecting different continents. The geographic distribution of the Mik antigen remains poorly characterized, highlighting an area requiring further investigation. [76]

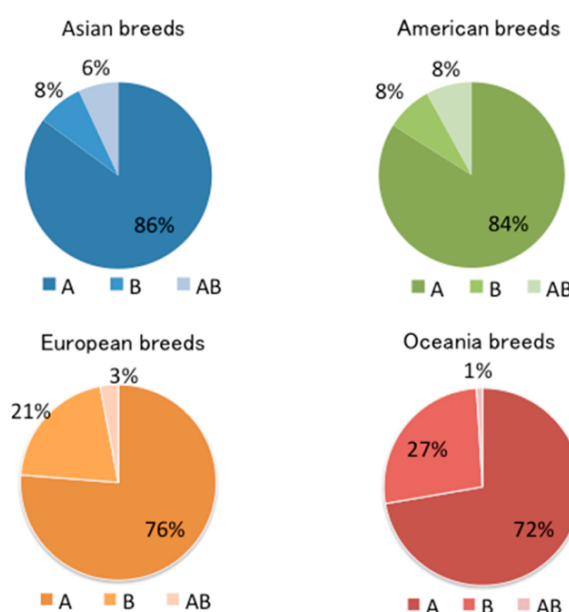


Figure 4: Prevalence of feline blood groups by geographic origin. [76]

4.3 Compatibility testing in canine and feline transfusion medicine

Blood typing in dogs and cats can be performed either using in-house assays or by sending samples to specialized commercial laboratories. Commercial laboratory testing based on the tube method is considered the reference technique because it provides more comprehensive information on erythrocyte antigen expression compared with most in-house methods. This approach is particularly relevant for canine blood donor screening and for cases requiring extended blood group characterization. [42]

4.3.1 Card agglutination test

The card agglutination test is a rapid, in-clinic method used for blood typing in both dogs and cats, based on a visible antigen–antibody agglutination reaction. A drop of the patient's blood is mixed with a species- and antigen-specific reagent on a dedicated card - a monoclonal anti-DEA 1 antibody in dogs, or anti-A and anti-B antibodies in separate wells for cats. The reaction is read visually: the presence of visible agglutination indicates a positive result for the corresponding antigen, whereas a homogeneous suspension indicates a negative result. [66] Although simple and rapid, its interpretation may be affected by factors such as autoagglutination, and its accuracy is lower compared with other available techniques. [77, 78]



Figure 5: Representative examples of DEA 1-negative (A) and DEA 1-positive (B) reactions.

4.3.2 Gel column technique

The gel column technique is a laboratory-based blood typing method that relies on the migration of red blood cells through a gel matrix containing a specific reagent. A diluted suspension of the patient's red blood cells is added to the top of a gel-filled microtube and centrifuged. If the corresponding antigen is present, agglutinated erythrocytes remain trapped at the top of the gel matrix, indicating a positive result; if absent, unagglutinated cells pass freely through the gel and form a compact pellet at the bottom of the tube, indicating a negative result. [66] The gel column technique has been adapted to erythrocyte antigens beyond DEA 1 in dogs, allowing extended blood typing and crossmatching within the same technique. [79] However, it requires specific equipment and standardized laboratory conditions, making it better suited to reference laboratories than to in-clinic emergency use.

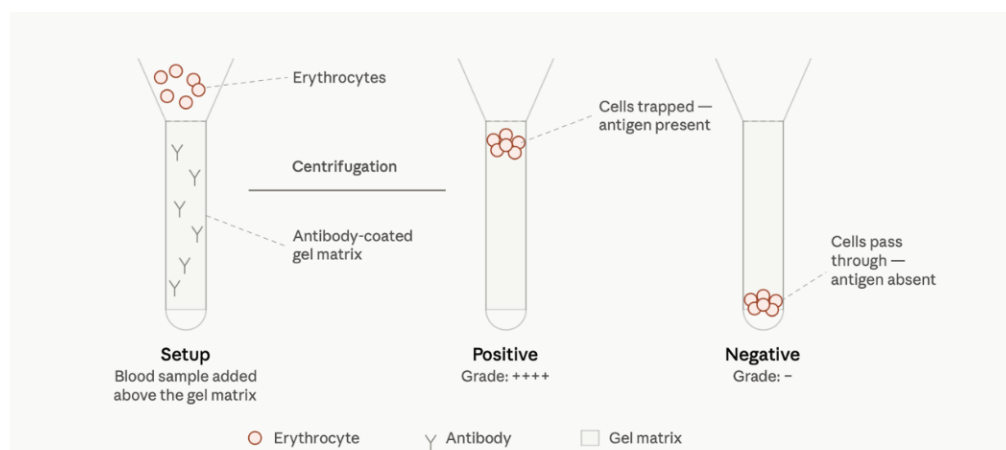


Figure 6: Principle of the gel column technique for blood typing

4.3.3 Immunochromatographic method

The immunochromatographic method relies on the lateral migration of blood cells along a membrane strip containing immobilized, antigen-specific antibodies. A diluted blood sample is applied and allowed to migrate through a reaction channel: if the corresponding antigen is present, erythrocytes are captured by the antibody and produce a visible signal at the test line, whereas in its absence the cells migrate freely without reaction. Depending on the platform, results are read either visually or with a dedicated analyzer. [66] Unlike the card agglutination test, this technique is not affected by autoagglutination, making it particularly useful for typing patients with immune-mediated hemolytic anemia. [42]

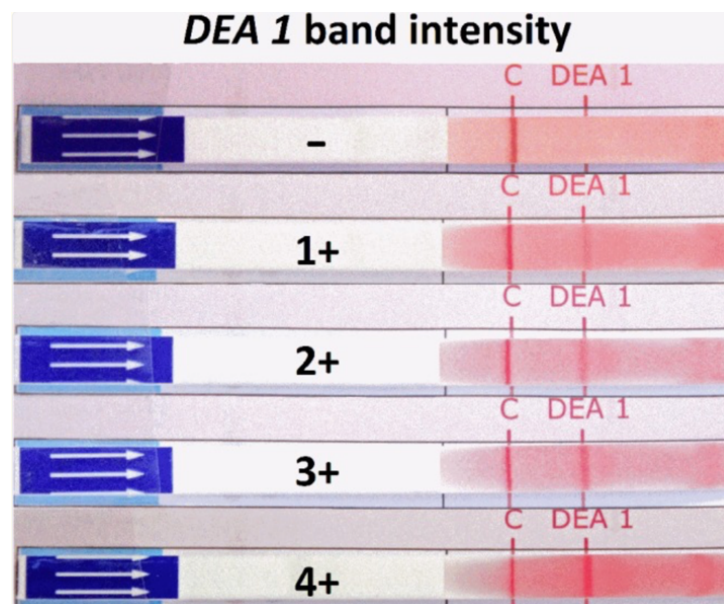


Figure 7: Immunochromatographic strip assay for canine DEA 1 blood typing. Representative examples of DEA 1-negative and DEA 1-positive results showing increasing band intensity from negative (-) to strongly positive (4+). [80]

Taken together, these comparative data indicate that, while the gel column technique offers the highest accuracy, both card and cartridge assays remain valuable for rapid in-clinic typing. [77]

4.3.4 Tube agglutination test

The tube agglutination test represents the original and most extensively validated blood typing method, and is still regarded as the reference technique against which newer platforms are compared. Blood is mixed with antiserum in a test tube, and the reaction is assessed for visible agglutination; because the reaction strength can be weak, an antiglobulin reagent (Coombs) may

be required to enhance detection. [77] Although it provides the most comprehensive information on erythrocyte antigen expression, the tube method is technically demanding, difficult to standardize, and dependent on reagents with limited availability, restricting its routine use to specialized reference laboratories rather than in-clinic settings. [42]



Figure 8: Example of tube agglutination testing for feline AB blood typing. In tube A (anti-A reagent) erythrocytes have agglutinated at the bottom, with a clear supernatant above, indicating a positive reaction. Tubes B (anti-B reagent) and C (control) show a uniform, diffuse red coloration throughout, indicating the absence of agglutination. [81]

Regardless of the method used, several factors may affect the accuracy of canine blood typing. Autoagglutination can interfere with agglutination-based assays and may prevent reliable interpretation even after saline washing of erythrocytes. In addition, severe anaemia may reduce the sensitivity of agglutination reactions because of the low concentration of red blood cells, while previous blood transfusions may produce mixed-field reactions due to the coexistence of donor and recipient erythrocytes. Therefore, whenever possible, blood samples for typing should be collected before transfusion. [66] Currently, commercial extended blood typing in dogs is available for selected antigens, including DEA 1, DEA 4, DEA 5, and DEA 7. In contrast, typing for

more recently described erythrocyte antigens, such as Dal and Kai remains restricted to selected research laboratories where specific reagents are available. [69]

4.4 Crossmatching in canine and feline transfusion medicine

Crossmatching provides a further level of pretransfusion compatibility testing beyond blood typing, as it directly assesses the serological compatibility between a specific donor and recipient by physically combining their blood in vitro before transfusion. Two reactions are typically performed: the major crossmatch, in which donor erythrocytes are mixed with recipient plasma to detect recipient antibodies capable of reacting against the donor's red blood cells, and the minor crossmatch, in which donor plasma is mixed with recipient erythrocytes to detect the reverse reaction. The major crossmatch is considered clinically more relevant, as it is directly implicated in the prevention of acute hemolytic transfusion reactions, whereas the minor crossmatch is generally regarded as less critical, particularly when small plasma volumes are transfused. [42]

Crossmatching relies on the same platforms used for blood typing: the tube, gel column, and immunochromatographic methods. [82] However, instead of reacting patient erythrocytes against a standardized commercial reagent, these platforms are adapted to detect agglutination or hemolysis between the actual blood of a specific donor and recipient. [42]

Clinically significant alloantibodies were traditionally considered uncommon in dogs, and as a result, many veterinary practitioners regarded crossmatching before a first blood transfusion as optional or unnecessary. [83] This assumption has been challenged by more recent evidence. A retrospective study evaluating 149 transfusion-naive dogs, each crossmatched against three potential donors, found that 17% of recipients were incompatible with one or two of the three donors, although all dogs were compatible with at least one. Furthermore, dogs that underwent crossmatching before transfusion showed a significantly greater increase in hematocrit afterward compared with dogs transfused without prior crossmatching. [84]

These findings are reinforced by a more recent prospective study that investigated exactly when alloantibodies appear after transfusion in dogs. Current guidelines recommend crossmatching only when an initial transfusion occurred more than four days earlier, or when transfusion history is unknown. To test this threshold, 21 anemic dogs were monitored daily for four days following

a DEA 1-compatible transfusion. More than half developed a positive crossmatch within this window, with antibodies detectable in some dogs after just one day. A further four dogs became positive later, between six and thirteen days post-transfusion. These results suggest that the four-day threshold may be too permissive, and support crossmatching before every subsequent transfusion. [85]

A comparable pattern of post-transfusion alloimmunization has also been documented in cats: in a prospective study of hospitalized anemic recipients, approximately 24% developed a positive major crossmatch as early as two days after their first AB-compatible transfusion, further supporting the inclusion of crossmatching in feline pretransfusion screening. [86]

The identification of the Mik antigen and its associated naturally occurring alloantibodies first prompted the recommendation to perform a crossmatch before a cat's first transfusion, although this practice has not been universally adopted. This recommendation was later supported by a retrospective study of 300 transfused cats, which found major crossmatch incompatibilities in nearly 15% of transfusion-naïve cats and in 27% of previously transfused cats. Cats that received crossmatch-compatible red blood cells experienced fewer febrile transfusion reactions than those transfused without crossmatching, although crossmatching was not associated with improved survival to hospital discharge. These findings support the recommendation to perform a crossmatch before every feline transfusion, including the first. [87]

5. Transfusion reactions

Transfusion reactions include a heterogeneous group of adverse events that may occur during or after the administration of blood products in dogs and cats. These reactions are broadly classified according to their time of onset: acute reactions typically develop during the transfusion or within the first 24 hours, whereas delayed reactions may manifest days to weeks later. This temporal distinction is clinically relevant, as it guides both the differential diagnosis and the intensity of patient monitoring required at each stage. [88]

5.1 Acute transfusion reaction

5.1.1 Acute hemolytic transfusion reaction (AHTR)

Acute hemolytic transfusion reaction (AHTR) is defined as an acute, immunologic or non-immunologic event resulting from accelerated destruction of transfused or recipient red blood cells, occurring during or within 24 hours of blood product administration. Immunologic AHTRs arise from major or minor blood type incompatibility between donor and recipient and represent a type II hypersensitivity reaction. Non-immunologic causes - such as thermal, osmotic, mechanical, or chemical damage to transfused erythrocytes - are only infrequently reported in the veterinary literature. In dogs and cats, the most common underlying cause of AHTR is a mismatched transfusion resulting from errors in recipient, donor, or unit identification and labeling, rather than a true failure of pretransfusion testing. [88]

5.1.2 Febrile non-hemolytic transfusion reaction (FNHTR)

Febrile non-hemolytic transfusion reaction (FNHTR) is defined as the development of fever exceeding 38°C, together with an increase of at least 1°C from pre-transfusion values, occurring during the transfusion or within four hours of its completion; alternatively, the presence of rigors or chills within the same time frame is also considered diagnostic, provided other causes of fever are excluded. Because these clinical signs are nonspecific, FNHTR remains largely a diagnosis of exclusion, requiring that underlying infection, acute hemolytic transfusion reaction, transfusion-related acute lung injury, and bacterial contamination of the blood unit first be ruled out. [88]

This reaction pattern has been confirmed by two recent large-scale prospective multicenter studies applying TRACS criteria in clinical practice. In dogs, evaluating over 1,500 transfusions across referral hospitals in the United States, United Kingdom, and Australia, the overall incidence of acute reactions was 8.9% for packed red blood cells and 4.5% for plasma products; FNHTR was the most frequent reaction associated with red blood cells (4%), whereas allergic reactions predominated with plasma administration (3.2%). Notably, the transfusion of red blood cell units stored for more than 28 days was associated with a substantially higher risk of both FNHTR and acute hemolytic reactions compared with fresher units, suggesting that storage-related changes in the blood product itself may contribute to reaction risk. [89] A comparable study in cats reported FNHTR as the most common reaction associated with red blood cell products, with an incidence of 5.7%; in this species, both increasing unit storage age and administration via an infusion pump, rather than a syringe driver, were identified as risk factors. [90]

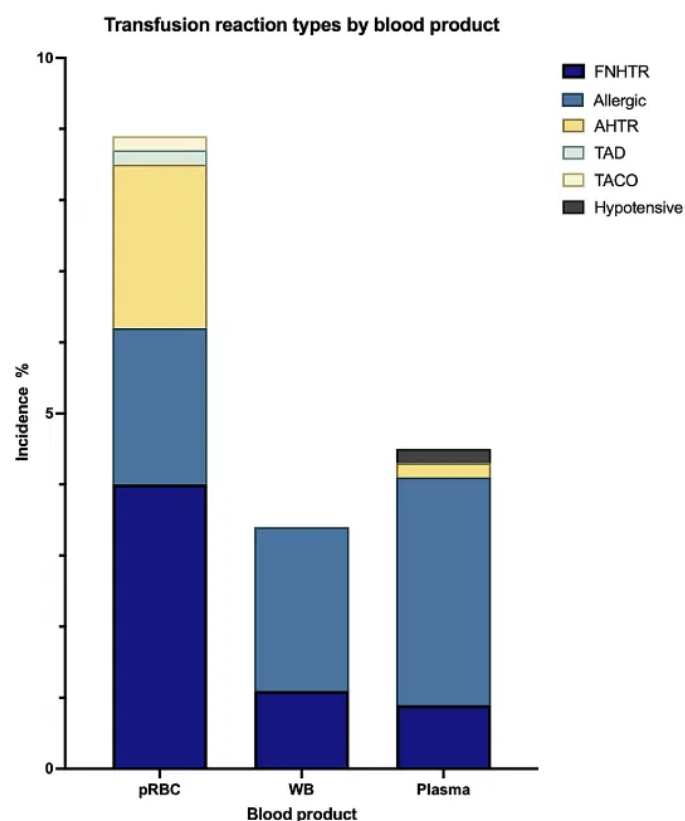


Figure 9: Transfusion reaction types by blood product in dogs. [89]

5.1.3 Allergic reactions

Allergic transfusion reactions are acute type I hypersensitivity reactions directed against an antigen contained within the transfused blood product, occurring during the transfusion or within four hours of its completion. The clinical presentation ranges from mild, self-limiting signs to life-threatening anaphylaxis, and differs between species: in dogs, cutaneous manifestations such as erythema, urticaria, pruritus, and facial or extremity angioedema predominate, whereas in cats respiratory signs are more typical, reflecting upper airway edema, bronchoconstriction, and excessive mucus production; gastrointestinal signs, including vomiting, may occur in both species. Allergic reactions appear to be reported more frequently in dogs than in cats, and are particularly associated with plasma administration rather than packed red blood cell transfusion, a pattern consistent with the higher incidence of allergic reactions observed with plasma products in the multicenter study discussed above. [88] In a retrospective study of nearly 1,000 transfusion events in dogs, allergic reactions accounted for approximately 9% of all documented transfusion reactions. Notably, premedication as a whole did not significantly reduce the overall occurrence of transfusion reactions; however, when analyzed individually, antihistamine premedication was specifically associated with a lower incidence of allergic reactions, suggesting that targeted rather than routine premedication protocols may be more clinically justified. [91]

5.1.4 Respiratory reactions (TACO, TRALI, TAD)

Respiratory reactions represent a less common but potentially serious category of acute transfusion reaction. They include transfusion-associated circulatory overload (TACO), transfusion-related acute lung injury (TRALI), and the more recently recognized transfusion-associated dyspnea (TAD). TACO results from volume overload and is characterized by acute respiratory distress developing within six hours of transfusion, often accompanied by evidence of left-sided heart failure or radiographic signs of pulmonary edema; patients with pre-existing cardiac or renal disease are considered particularly susceptible. TRALI, by contrast, is an immunologic reaction resulting from antigen–antibody interactions within the pulmonary vasculature, producing acute hypoxemia with non-cardiogenic pulmonary edema in the absence of pre-existing lung injury or evidence of volume overload. TAD is a more recently introduced category, used to capture respiratory transfusion reactions that do not meet the diagnostic criteria for either TACO or TRALI; it has not yet been specifically applied in veterinary medicine,

and cases in dogs and cats have been described only in general terms of post-transfusion respiratory distress. These conditions remain poorly characterized in veterinary patients, and the veterinary literature specifically defining and distinguishing them in dogs and cats is still limited. [88] In a prospective study using echocardiography to assess anemic dogs and cats before and after transfusion, evidence of volume overload was common in both species regardless of transfusion, yet clinical TACO developed in only one of 40 patients, suggesting that echocardiographic signs of overload do not necessarily predict clinical circulatory overload and that transfusion is generally well tolerated even in at-risk patients. [92]

5.1.5 Citrate toxicity/ hypocalcemia

As already discussed in the context of massive transfusion, citrate toxicity is an acute, non-immunologic reaction resulting from the rapid administration of large volumes of citrate-anticoagulated blood. Citrate chelates ionized calcium, and when it accumulates faster than it can be metabolized (especially in patients with hepatic dysfunction, severe hypothermia or shock), it produces clinically significant systemic hypocalcemia within hours of transfusion onset. [88] In a large case series evaluating the etiology of calcium disturbances in nearly 2,000 dogs and cats, transfusion-related citrate toxicity was identified as the leading cause of toxicity-associated hypocalcemia in both species, accounting for approximately 63% of toxicity-related cases in dogs and 71% in cats. [93]

5.2 Delayed transfusion reactions

5.2.1 Delayed hemolytic and delayed serologic transfusion reactions (DHTR/DSTR)

Delayed hemolytic transfusion reaction (DHTR) is defined as a delayed, immunologic or non-immunologic reaction resulting from lysis or accelerated clearance of transfused red blood cells, occurring between 24 hours and 28 days after transfusion. Immunologic DHTRs typically arise from a secondary immune response directed against donor erythrocyte antigens. A closely related entity, the delayed serologic transfusion reaction (DSTR), refers to the development of clinically significant antibodies against the transfused product within the same time frame, but without detectable hemolysis. [88] These definitions align closely with the alloimmunization patterns already described in the context of crossmatching: a substantial proportion of dogs and

cats develop detectable alloantibodies within days of a first transfusion, which explains why repeated crossmatching is recommended even when an initial transfusion appeared uneventful.

5.3 Prevention

Several strategies have been proposed to reduce the risk of transfusion reactions, although the strength of supporting evidence varies considerably. [94]

Regarding feline blood collection, there is currently insufficient evidence to recommend closed collection systems over semi-closed or open ones specifically to reduce the risk of transfusion-transmitted infection. [94]

Storage duration of red blood cell units has been more consistently associated with reaction risk. In a retrospective study of 210 clinical canine transfusion cases, the age of stored red blood cell products was significantly associated with an increased risk of transfusion-related hemolysis, although no association was found with fever or overall mortality. [95] Consistent with this, TRACS guidelines suggest considering fresher red blood cell products in dogs with sepsis or hemolytic anemia, and recommend fresh whole blood (<24 hours) or red blood cells stored for less than 7 days in patients at increased risk of hyperammonemia, such as those with hepatic dysfunction or requiring massive transfusion; however, stored products appear safe with regard to hyperammonemia in patients with normal liver function. [94] Indeed, early studies showed that although ammonia concentrations rise markedly in stored canine red blood cell units over time, plasma ammonia levels in anemic dogs without hepatic disease remained normal following transfusion. [96]

Regarding pretransfusion testing, current evidence does not support a benefit of crossmatching prior to a first transfusion in dogs, whereas in cats crossmatching before the first transfusion is considered essential to reduce the risk of an acute hemolytic reaction, consistent with the naturally occurring alloantibodies discussed previously. [94] Xenotransfusion of canine blood to cats may be lifesaving in an emergency when feline blood products are unavailable, but it carries a risk of severe, potentially fatal transfusion reactions; owners should be informed of this risk and, when feasible, referral for compatible feline blood products is preferable. [94] This risk has been documented in a large study of approximately 50 cats receiving canine blood, in which 43% developed a transfusion reaction, and 20% died or were euthanized within 24 hours; despite this,

median PCV increased substantially within 12 hours of transfusion, reflecting its potential short-term efficacy in genuine emergencies. Hemolysis following xenotransfusion is generally expected to occur between 1 to 6 days after transfusion, underscoring the importance of close post-transfusion monitoring in these patients. [97]

Finally, regarding infusion technique, TRACS guidelines suggest an initially slow infusion rate during the first 15 minutes, followed by an increase if no adverse effects are observed, with slower rates favored in euvoletic patients or those with concurrent cardiac or renal disease. [94]

5.4 Monitoring

Given the potential severity of transfusion reactions, close patient monitoring is essential to allow the earliest possible detection of a reaction and to minimize its clinical impact. Vital parameters should be assessed particularly closely during the initial phase of the transfusion, as this represents the period of highest risk for a severe reaction to develop. Feline-specific guidelines recommend checking vital signs as frequently as every 5 minutes during the first 30 to 60 minutes of administration. [98] Despite this, transfusion monitoring practices had not previously been standardized in veterinary medicine, prompting the development of a dedicated monitoring form as part of the TRACS guidelines. This form tracks the vital parameters most likely to signal an evolving reaction. After the first hour, vital parameters are generally checked hourly; however, the patient should be monitored visually much more frequently and, ideally, never left unattended during the transfusion. A multiparameter monitor can help minimize repeated handling, which is particularly advantageous in cats. Monitoring is continued for up to 24 hours after the transfusion ends, since acute reactions can still develop within this window. Finally, packed cell volume or hematocrit may be assessed immediately after transfusion to evaluate its efficacy. [94]

Start time: _____ Date: _____ Person starting transfusion: _____

	Time	Infusion rate ml/hr	Resp. rate	Pulse rate	MM Colour & CRT	Temp °C	Mentation	S/D/M blood pressure	Serum/plasma/urine colour	Angiodema/Erythema/Pruritis (Y/N)	Vomit or diarrhea (Y/N)	Other concerns
Pre-transfusion												
5 mins												
15 mins.												
30 mins.												
60 mins.												
2 hours												
3 hours												
4 hours												
15 mins post transfusion												
1 hour post transfusion												
24 hour post transfusion												

Finish time: _____ Volume infused: _____ Post-transfusion PCV & time: _____

Figure 10: Example of monitoring form used during transfusion in dogs and cats [94]

5.5 Diagnosis and management

Regardless of the specific clinical signs observed, the general approach to a suspected transfusion reaction follows a consistent sequence: the transfusion should be stopped or paused, vital parameters reassessed, and the severity of the reaction determined before deciding whether the transfusion can be safely resumed. Mild, self-limiting signs - such as isolated fever or mild cutaneous pruritus - may allow the transfusion to continue at a reduced rate under close observation, whereas more severe or progressive signs, particularly those suggestive of an acute hemolytic reaction, anaphylaxis, or respiratory compromise, warrant immediate discontinuation and targeted treatment. [99]

Management is largely supportive and tailored to the type of reaction suspected. Febrile reactions are generally managed conservatively once more serious causes of fever, such as acute hemolysis or bacterial contamination, have been excluded. Allergic reactions typically respond to antihistamine administration, with glucocorticoids or epinephrine reserved for more severe or anaphylactic presentations. Suspected acute hemolytic reactions require prompt supportive care, including intravenous fluid therapy to maintain renal perfusion, alongside close monitoring for disseminated intravascular coagulation and acute kidney injury. Respiratory reactions are managed according to the suspected underlying mechanism: oxygen supplementation and, in cases of suspected volume overload, diuretic therapy and reduction of the infusion rate, whereas suspected TRALI is managed primarily with supportive respiratory care. [99]

Retrospective study

6. Objective of the study

Several studies have investigated the predictive value of admission laboratory parameters for transfusion requirement in traumatized dogs. The Trauma-Associated Severe Hemorrhage (TASH) score, originally developed in human trauma patients, has shown promise in identifying dogs at higher risk of requiring transfusion, with base excess and the presence of free abdominal fluid emerging as particularly informative components. [55] Admission base excess alone has similarly been shown to predict both transfusion requirement and mortality in dogs with blunt trauma, [17] while admission PCV and total solids, although highly specific, have demonstrated limited sensitivity as standalone predictors. [52]

The aim of this study was to evaluate whether specific laboratory parameters, measured at hospital admission, could serve as early predictors of the need for blood transfusion in dogs and cats presenting with traumatic injury. Early identification of patients likely to require transfusion remains clinically challenging, as conventional cardiovascular parameters may not adequately reflect the severity of hemorrhage in the initial stages of trauma. By evaluating the association between admission laboratory values and subsequent transfusion requirement, this study aimed to contribute to the identification of accessible, rapidly available markers that may assist clinicians in the early recognition of patients at higher risk, supporting more timely transfusion decision-making in the emergency setting, with the additional goal of exploring whether predictive laboratory parameters differ between dogs and cats.

7. Materials and methods

The study was conducted retrospectively on a population of dogs and cats referred to the Ospedale Veterinario Universitario Didattico (OVUD) of the Department of Veterinary Science of the University of Parma. The study included dogs and cats between January 2023 and June 2026 after a witnessed or suspected traumatic event.

Dogs were identified through a keyword-based search of the hospital database, selecting all canine patients hospitalized for at least one day following a witnessed or suspected traumatic event during the study period. Dogs were excluded if no complete medical record was available, or if no diagnostic test results could be retrieved. Of the 103 traumatized dogs initially identified, 95 met the inclusion criteria and were included in the final study population.

Cats were identified using the same criteria. Cats were excluded if no complete medical record was available, or if no diagnostic test results could be retrieved. Of the 118 traumatized cats initially identified, 106 met the inclusion criteria and were included in the final study population.

For each patient, different parameters were collected, including signalment, history, physical examination and medical records. Regarding signalment and anamnesis, the following were recorded: species, breed, sex, age, body weight and type of trauma. The etiology of the trauma was classified into six categories: motor vehicle accident, bite injury, fall from height, crush injury, gunshot trauma and unknown.

Following history collection, several diagnostic tests were performed and included in the study: venous blood gas analysis, complete blood count, serum biochemistry profile, thoracic and abdominal focused assessment with sonography for trauma (TFAST/AFAST) and a coagulation panel. Not all patients underwent the full diagnostic panel; however, all cases with at least one test available were included in the study.

The primary outcome of interest was whether the patient received a blood transfusion during hospitalization. When available, the reason for transfusion was also recorded from the medical records.

Although complete blood count, venous blood gas analysis, biochemistry profile and coagulation data were collected in full for every patient, only a limited number of parameters were considered for the purposes of this study:

- Hematocrit (%)
- Albumin (g/dL)
- Total protein (g/dL)
- Creatinine (mg/dL)
- Alanine aminotransferase (ALT) (U/L)
- pH
- Glucose (mg/dL)
- Base excess (mmol/L)
- Lactate (mmol/L)
- PT (s)
- aPTT (s)

For patients in which blood pressure and heart rate were assessed, the Shock Index (SI) was also calculated.

For each animal, the type of injury was classified into the following trauma categories: thoracic trauma, abdominal trauma, head trauma and orthopedic trauma.

Trauma category	Subcategories
Thoracic trauma	Pneumothorax, pulmonary contusion, diaphragmatic hernia, hemothorax
Abdominal trauma	Hepatic contusion, splenic contusion, urinary bladder contusion/ rupture, abdominal hernia, hemoabdomen
Orthopedic trauma	Pelvic/ sacral fractures or luxations, cranial fractures, forelimb fractures/ luxations, hindlimb fractures/ luxations

Table 10: Classification of trauma type and associated subcategories.

Head trauma was recorded as a binary variable (present/absent), based on the presence of clinical signs consistent with cranial injury.

7.1 Statistical analysis

Data were collected in electronic spreadsheets (Microsoft Excel, Microsoft Corporation, Redmond, WA, USA) and imported into a statistical software package (MedCalc® Statistical Software, Version 20.110, Ostend, Belgium) for analysis. To make the study populations more homogeneous for statistical purposes, descriptive and comparative analyses were performed separately for dogs and cats. Data distribution was assessed using the Shapiro-Wilk test. Continuous variables were expressed using standard descriptive statistics and presented as mean $\pm$ standard deviation or median and range (minimum-maximum), based on normal or non-normal data distribution, respectively. Comparisons between transfused and non-transfused animals were performed using Welch's t-test for normally distributed variables and the Mann-Whitney U test for non-normally distributed variables. A p-value < 0.05 was considered statistically significant.

8. Results

8.1 Dogs

A total of 95 traumatized dogs were therefore included in the final study population.

Regarding breed distribution, mixed-breed dogs 28/95 were the most represented group (29%), followed by Maltese, Pinscher, Chihuahua and Jack Russell Terrier (4% each), Cane Corso, Maremma Sheepdog and Lagotto Romagnolo (3% each), the remaining breeds were each represented by a single dog. The median age of the dogs was 7.6 years (range from 2.5 months to 17.2 years).

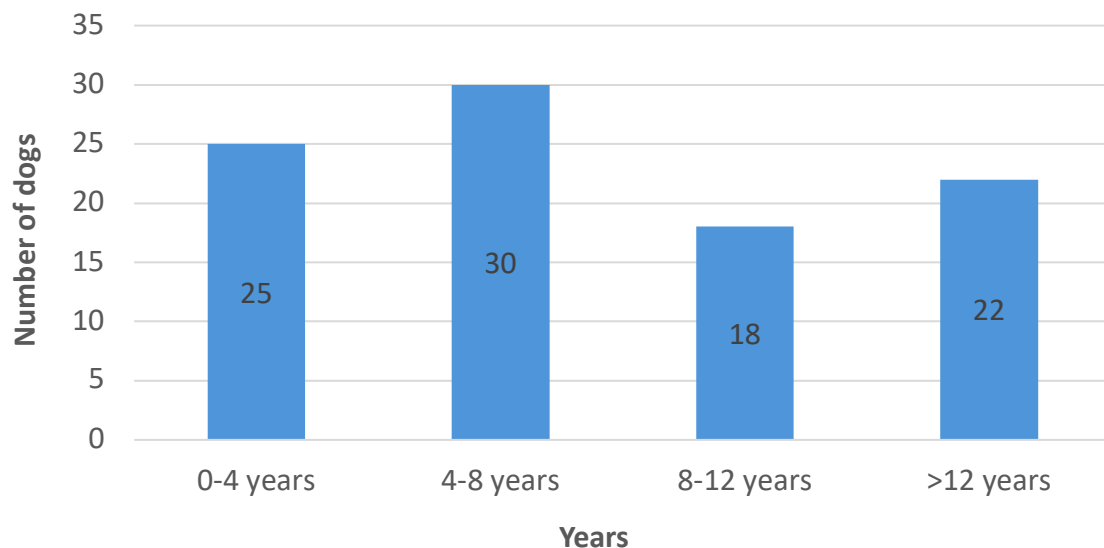


Figure 11: Distribution of age in the canine population.

Mean age and body weight also differed according to sex and reproductive status. In the study population, 43/95 dogs were female (45%), of which 19/43 were sterilised, and 52/95 (55%) were male, of which 8/52 were castrated. Sterilised females were the oldest group (9 years), while intact females were the youngest (5.6 years). Castrated males had the highest mean weight (18.7 kg) compared with the other groups. The median weight was 14.7 kg (range from 2.3 kg to 60 kg).

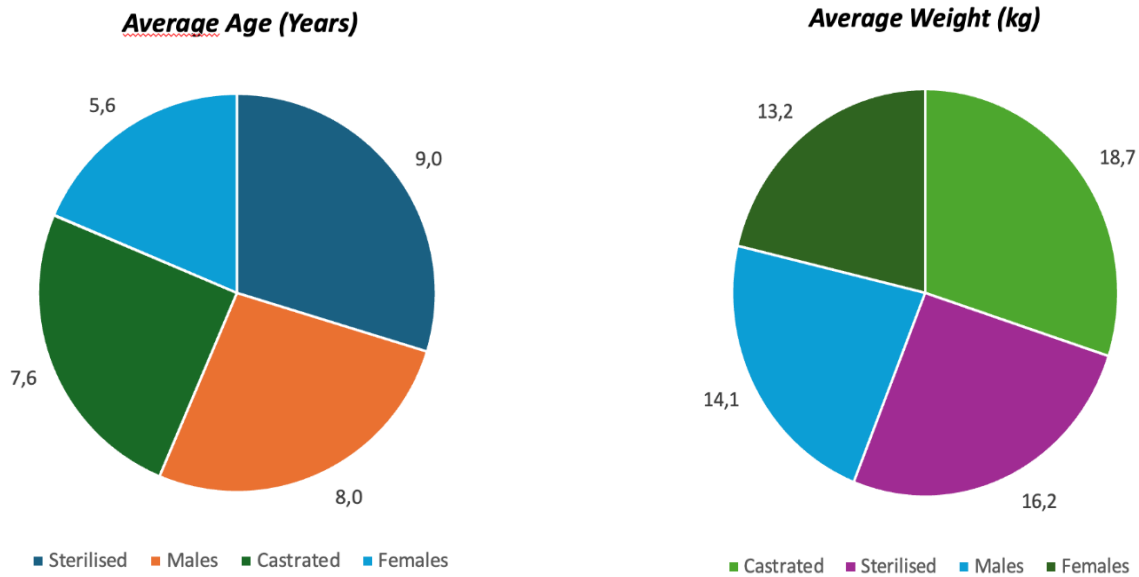


Figure 12: Mean age and mean weight according to sex and reproductive status.

Regarding the etiology of the trauma, motor vehicle accident was the most frequent cause of trauma with 40/95 cases (42%), followed by bite injury 32/95 (34%), fall from height 13/95 (14%), unknown 6/95 (6%), crush injury 3/95 (3%) and gunshot wound 1/95 (1%).

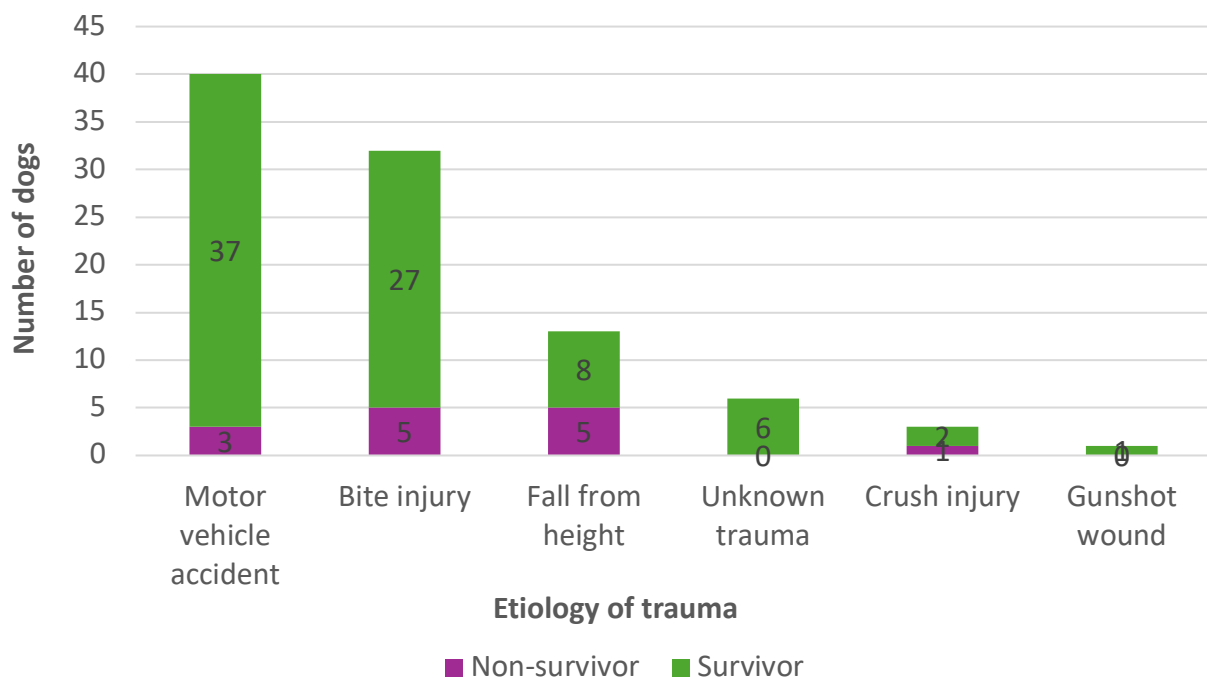


Figure 13: Distribution of trauma etiology and outcome (survivor/ non- survivor) in the canine population.

Across the study population, the distribution of injuries varied by anatomical region, including thoracic, abdominal, head and orthopedic. Orthopedic trauma was the most frequently observed, affecting 46/95 dogs, followed by abdominal trauma 18/95 and thoracic trauma 18/95, and head trauma 10/95. Despite being the least common category, head trauma was associated with the highest proportional mortality (2/10, 20%), followed by orthopedic trauma (6/46, 13%) and abdominal trauma (2/18, 11%), while thoracic trauma showed the lowest proportional mortality (1/18, 6%).

Of the 95 dogs included in the study, 14 (15%) received a blood transfusion. The reason for transfusion was documented in 10 of these 14 dogs; septic shock was the most frequently reported indication, in 7 cases, while suspected or confirmed acute traumatic coagulopathy was reported in 2 cases, and multi-organ damage in 1 case. Fresh frozen plasma was the most administered product (14/14 dogs), and 1 of these dogs also received packed red blood cells. Mortality among transfused dogs was notably high (6/14, 43%).

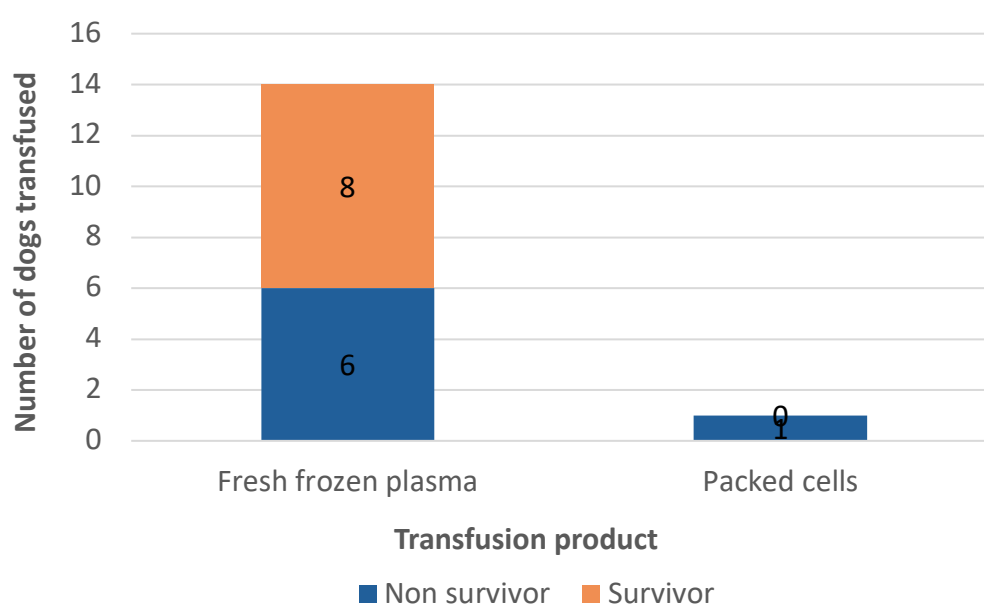


Figure 14: Blood products administered to transfused dogs, by short-term outcome.

All transfused dogs were monitored during transfusion following TRACS guidelines, and no transfusion reactions were recorded.

Of the 14 transfused dogs, DEA 1 typing was known in only 7 dogs prior to transfusion, of which 6 were DEA 1-positive and 1 was DEA 1-negative; blood type was unknown in the other 7 dogs (50%).

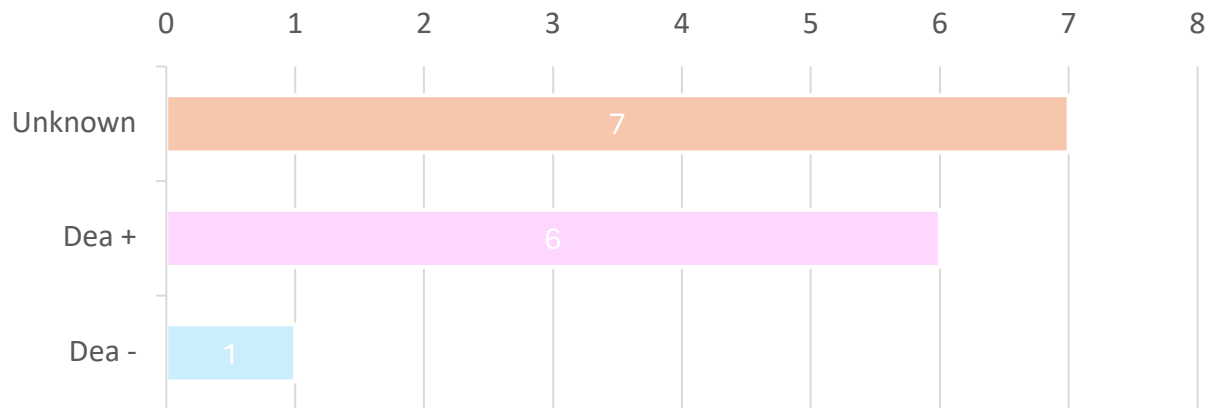


Figure 15: DEA 1 typing among transfused dogs.

Among the 14 transfused dogs, motor vehicle accident was the most common underlying trauma (7 dogs), followed by bite injury (6 dogs) and fall from height (1 dog). Mortality varied by etiology: 2 of 7 dogs (29%) with motor vehicle accident trauma died, 3 of 6 dogs (50%) with bite injury, and the single dog with fall from height did not survive.

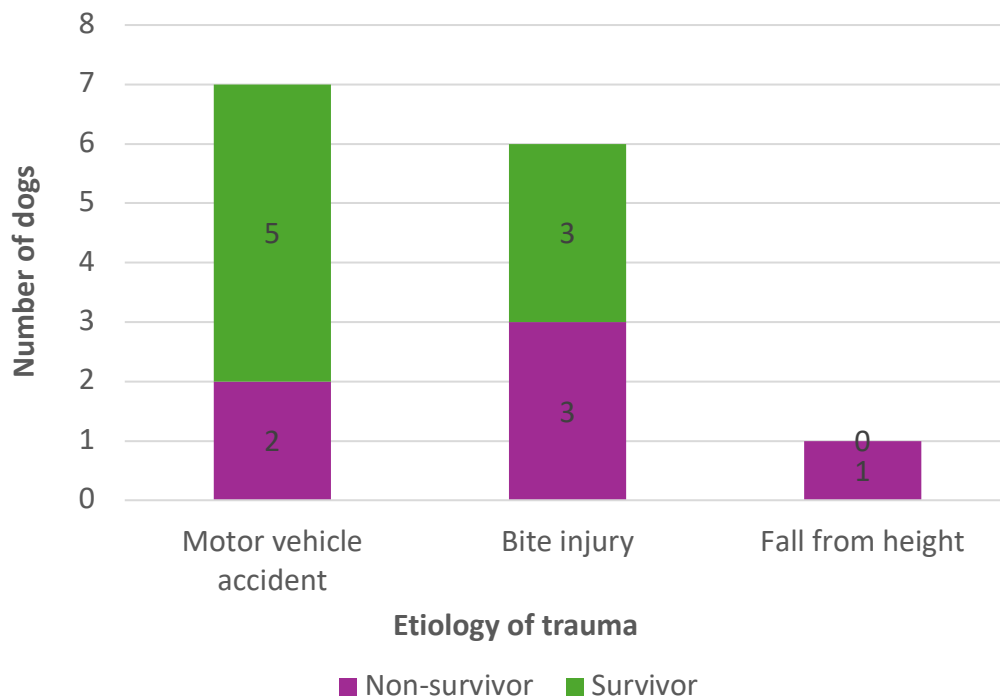


Figure 16: Etiology of trauma among transfused dogs, by short-term outcome (survivor/non-survivor).

A-FAST was performed in 57 of 95 dogs (60%), of which 7 (12%) tested positive. Etiology among A-FAST-positive dogs included motor vehicle accident (3 cases), unknown (2 cases), and bite injury (2 cases). These cases most commonly showed free abdominal fluid consistent with hemoabdomen; one additional case revealed a finding of uterine fluid accumulation. Among the A-FAST positive dogs, 1 received a blood transfusion (fresh frozen plasma) and subsequently died; this was the only fatality among A-FAST positive dogs, and the underlying trauma in this case was a bite injury.

T-FAST was performed in 52 of 95 dogs (55%), of which 4 (8%) tested positive, most commonly showing mild pleural effusion; all four cases resulted from motor vehicle accidents. Among the T-FAST positive dogs, 1 received a blood transfusion and survived; no deaths occurred among T-FAST positive dogs.

Among the clinical-pathological and severity variables evaluated, seven parameters showed a statistically significant difference between transfused and non-transfused dogs. These variables are described individually in this section and presented as box plots in Figures 17-23.

Total protein was available for 91 of the 95 dogs (96%). Among these, 14 were transfused dogs and 77 were non-transfused dogs. The median total protein was 5.11 g/dL (range 3.85-6.6) in transfused dogs, and 5.9 g/dL (range 4.03-8) in non-transfused dogs. Total protein concentration was significantly lower in transfused dogs (Mann-Whitney test, $p = 0.008$).

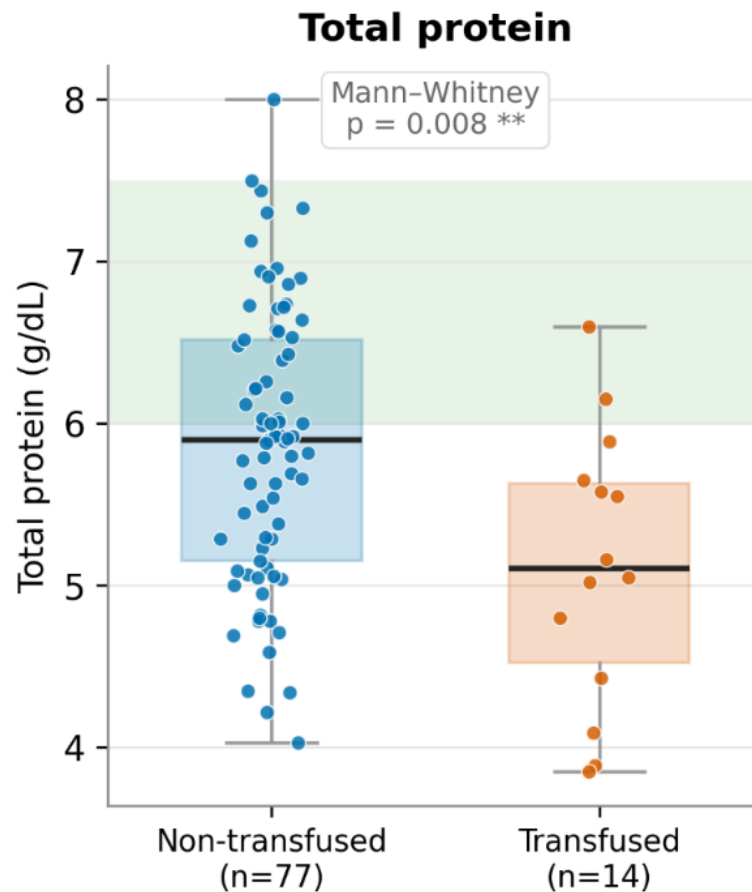


Figure 17: Box plot comparing total protein between non-transfused (blue, $n=77$) and transfused (orange, $n=14$) dogs. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.008$).

Albumin was available for 91 of the 95 dogs (96%). Among these, 14 were transfused dogs and 77 were non-transfused dogs. The median albumin was 2.52 g/dL (range 1.98-3.28) in transfused dogs, and 2.93 g/dL (range 2.1-4.33) in non-transfused dogs. Albumin concentration was significantly lower in transfused dogs (Mann-Whitney test, $p = 0.003$)

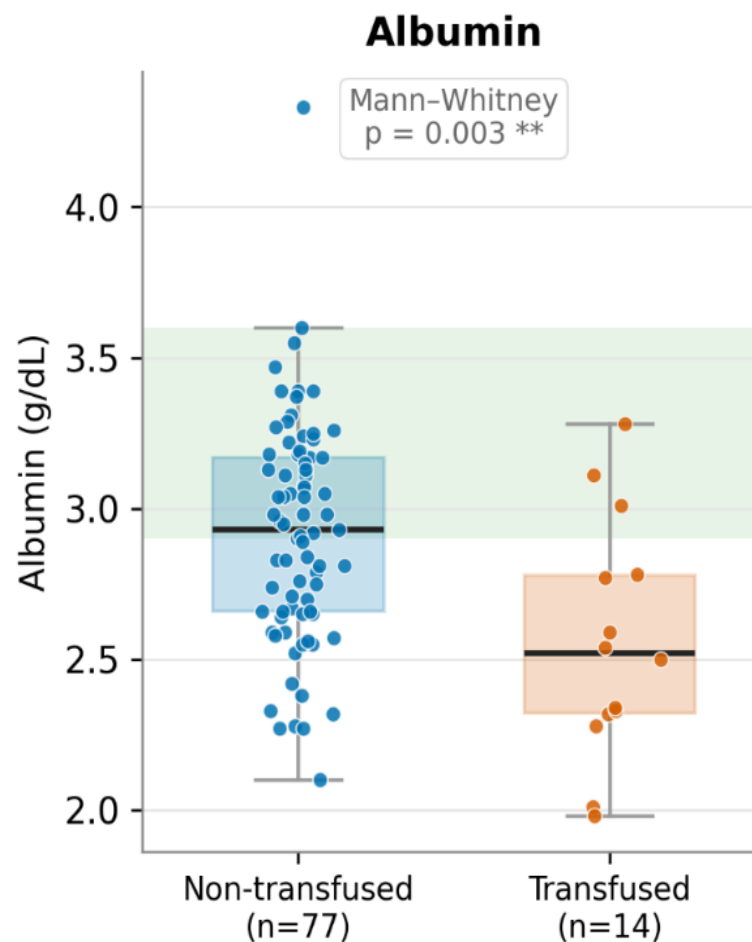


Figure 18: Box plot comparing albumin between non-transfused (blue, $n=77$) and transfused (orange, $n=14$) dogs. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.003$).

Creatinine was available for 91 of the 95 dogs (96%). Among these, 14 were transfused dogs and 77 were non-transfused dogs. The median creatinine was 1.2 mg/dL (range 0.51-2.6) in transfused dogs, and 0.94 mg/dL (range 0.4-2.9) in non-transfused dogs. Creatinine concentration was significantly higher in transfused dogs (Mann-Whitney test, $p = 0.046$).

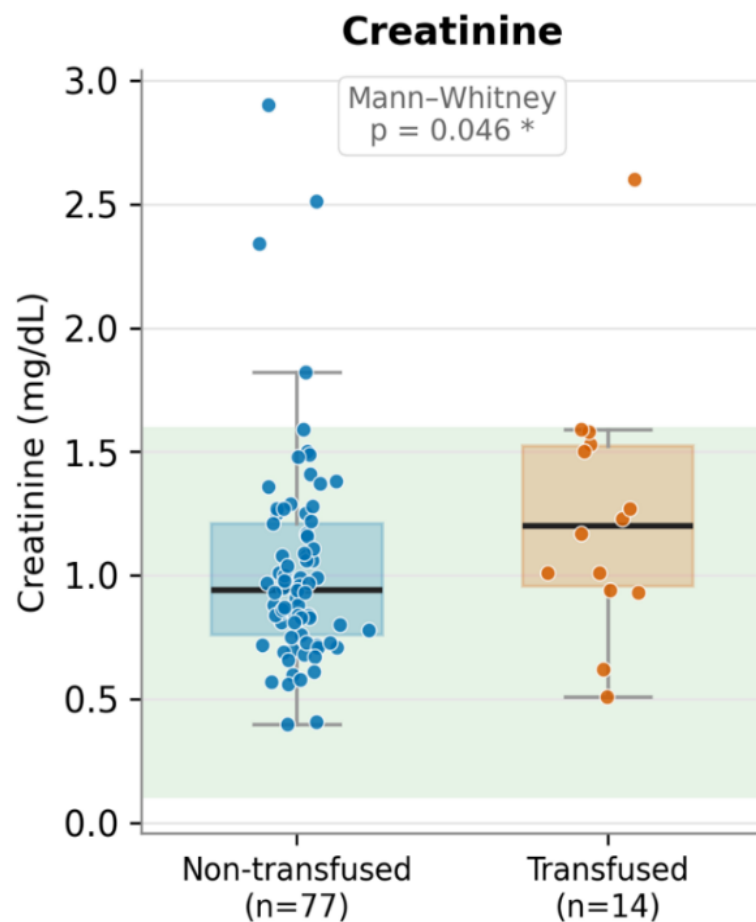


Figure 19: Box plot comparing creatinine between non-transfused (blue, $n=77$) and transfused (orange, $n=14$) dogs. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.046$).

Venous blood pH was available for 92 of the 95 dogs (97%). Among these, 14 were transfused dogs and 78 were non-transfused dogs. The median pH was 7.29 (range 7.05-7.39) in transfused dogs, and 7.35 (range 7.08-7.46) in non-transfused dogs. Venous blood pH was significantly lower in transfused dogs (Mann-Whitney test, $p = 0.006$).

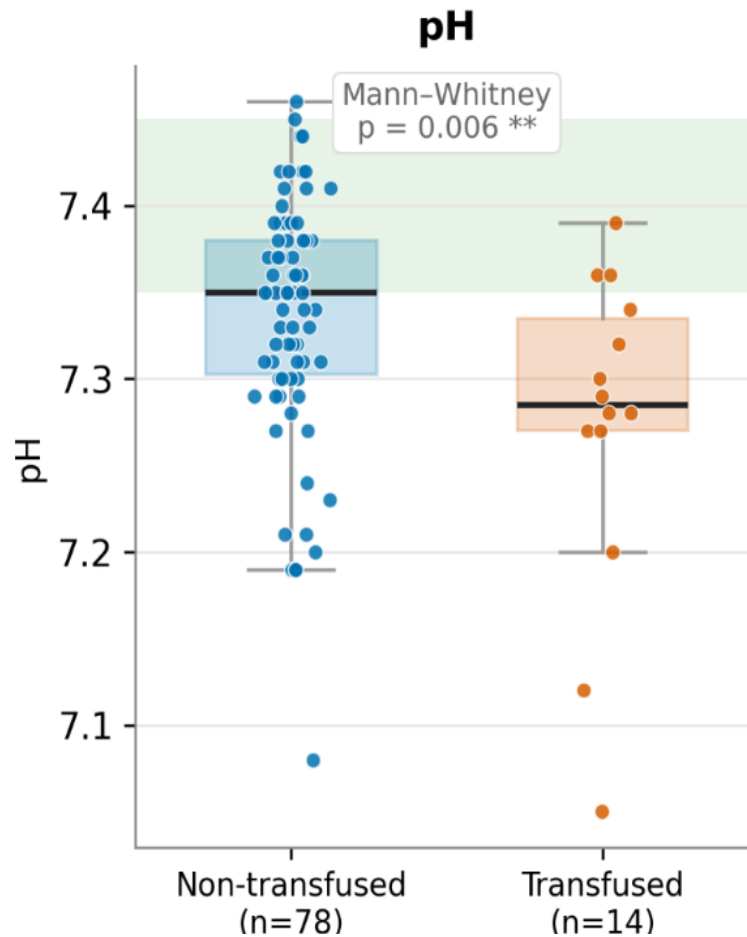


Figure 20: Box plot comparing venous blood pH between non-transfused (blue, $n=78$) and transfused (orange, $n=14$) dogs. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.006$).

Glycemia was available for 91 of the 95 dogs (96%). Among these, 14 were transfused dogs and 77 were non-transfused dogs. The median glycemia was 165.5 mg/dL (range 38-374) in transfused dogs, and 112 mg/dL (range 43-738) in non-transfused dogs. Glycemia was significantly higher in transfused dogs (Mann-Whitney test, $p = 0.008$).

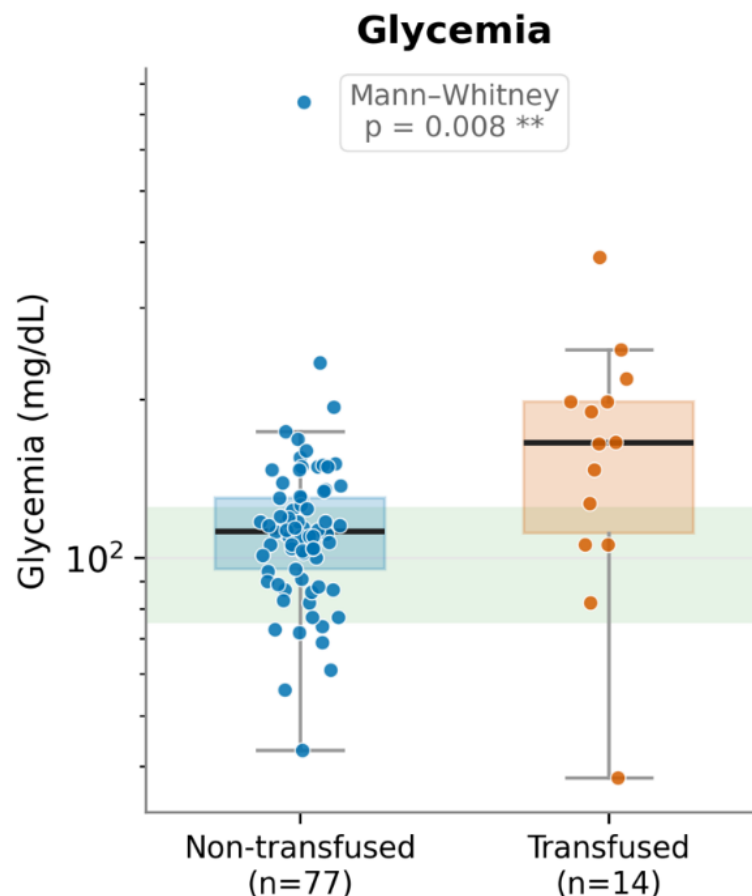


Figure 21: Box plot comparing glycemia between non-transfused (blue, $n=77$) and transfused (orange, $n=14$) dogs, displayed on a logarithmic scale. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.008$).

Lactate concentration was available for 92 of the 95 dogs (97%). Among these, 14 were transfused dogs and 78 were non-transfused dogs. The median lactate concentration was 3.55 mmol/L (range 1.5-9.6) in transfused dogs, and 2.5 mmol/L (range 0.6-14.4) in non-transfused dogs. Lactate concentration was significantly higher in transfused dogs (Mann-Whitney test, $p = 0.036$).

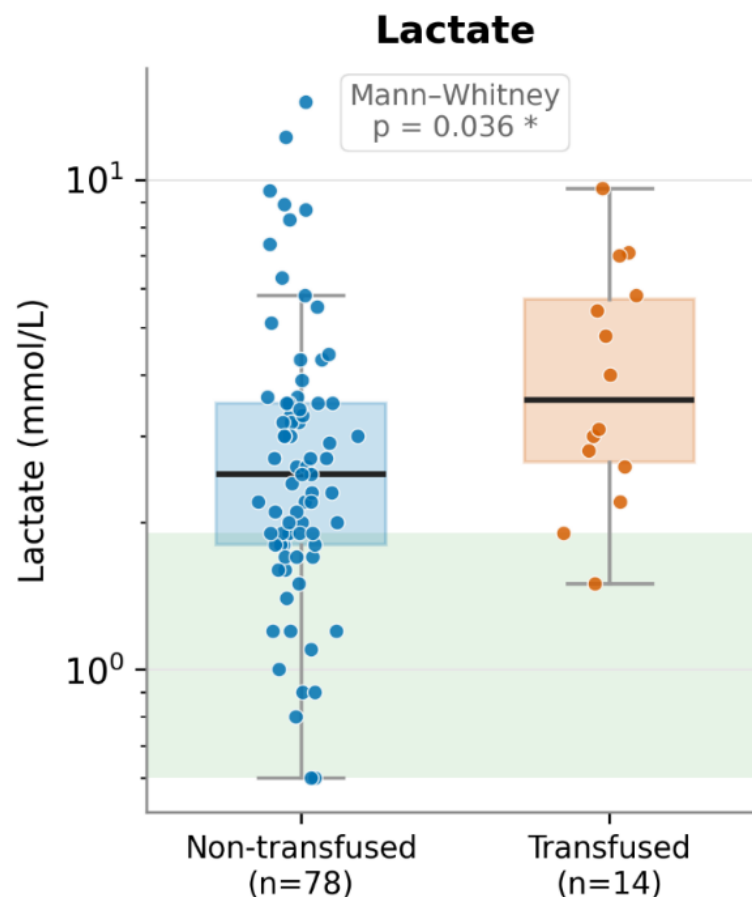


Figure 22: Box plot comparing lactate concentration between non-transfused (blue, $n=78$) and transfused (orange, $n=14$) dogs, displayed on a logarithmic scale. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.036$).

With the clinical findings recorded at the admission, the Shock Index (SI) was calculated for 82 of the 95 dogs (86%). Among these, 9 were transfused dogs and 73 were non-transfused dogs. Shock Index was significantly higher in transfused dogs (Mann-Whitney test, $p = 0.001$). Among the 82 dogs with SI available, 12 died. 11 dogs had a Shock Index greater than 1.5, of which 3 died. Among these 11 dogs, 6 received fresh frozen plasma, including all the 3 dogs that died.

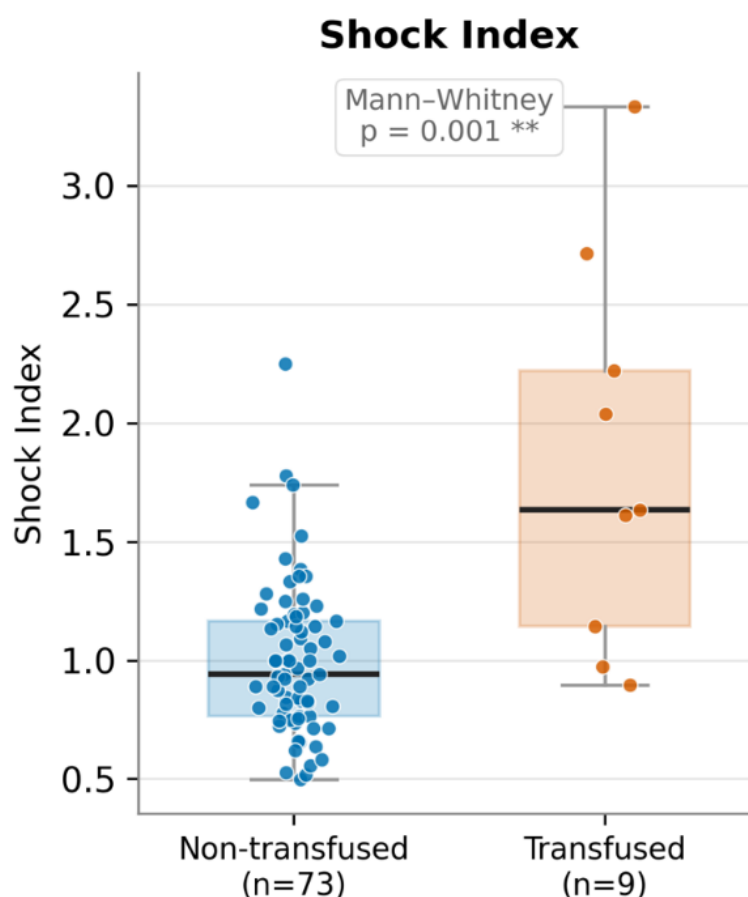


Figure 23: Box plot comparing Shock Index between non-transfused (blue, $n=73$) and transfused (orange, $n=9$) dogs. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. Mann-Whitney test was used for comparison ($p = 0.001$).

No statistically significant differences were found between transfused and non-transfused dogs for hematocrit ($p = 0.853$), ALT ($p = 0.800$), base excess ($p = 0.109$), PT ($p = 0.444$), and aPTT ($p = 0.389$). A summary of all clinical-pathological findings and severity scores, including both significant and non-significant variables, is provided in Table 11.

Variable	RI	Dogs	Trasfused	Non-trasfused	P value
Hematocrit	39.0-54.0	44.70 ± 7.04	45.03± 7.04	44.64± 7.08	0.853
ALT (U/L)	22-78	144 (18-3444)	259 (36-1787)	141 (18-3444)	0.800
Total protein (g/dL)	6.0-7.5	5.8 (3.85-8)	5.11 (3.85-6.6)	5.9 (4.03-8)	0.008
Albumin (g/dL)	2.9-3.6	2.89 (1.98-4.33)	2.52 (1.98-3.28)	2.93 (2.1-4.33)	0.003
Creatinine (mg/dL)	0.1-1.6	0.97 (0.4-2.9)	1.2 (0.51-2.6)	0.94 (0.4-2.9)	0.046
pH	7.35-7.45	7.35 (7.05-7.46)	7.29 (7.05-7.39)	7.35 (7.08-7.46)	0.006
Glycemia (mg/dL)	75-125	114 (38-738)	165.5 (38-374)	112 (43-738)	0.008
Base Excess (mmol/L)	-2 – +2.5	-4.4 (-15.3/3.3)	-5.7 (-15.1/3.3)	-4.1 (-15.3/1.7)	0.109
Lactate (mmol/L)	0.6-1.9	2.6 (0.6-14.4)	3.55 (1.5-9.6)	2.5 (0.6-14.4)	0.036
PT	9-15	8.6 (6-18.1)	8.55 (6.9-14.4)	8.6 (6-18.1)	0.444
aPTT	9-17	12.4 (9-31.1)	12.9 (10.7-19.9)	12.35 (9-31.1)	0.389
Shock Index	-	1 (0.5-3.33)	1.63 (0.9-3.33)	0.94 (0.5-2.25)	0.001

Table 11: Clinical-pathological findings and severity scores in transfused (n=14) and non-transfused (n=81) dogs. Data are reported as mean ± standard deviation for hematocrit, and as median (range) for all other variables. P values were calculated using the Mann-Whitney U test for all variables, except hematocrit, for which Welch's t-test was used.

To further evaluate the predictive value of the seven variables found to differ significantly between transfused and non-transfused dogs, univariate logistic regression analysis was performed (Table 12). Total protein, albumin, pH, and Shock Index remained significant predictors of transfusion requirement. Creatinine, glycemia, and lactate were not confirmed as significant predictors on logistic regression, despite showing significant differences on Mann-Whitney testing.

Variable	Odds ratio	IC 95%	P value
Total protein (g/dL)	0.35 (per 1g/dL)	0.16-0.75	0.007
Albumin (g/dL)	0.06 (per 1g/dL)	0.01-0.38	0.003
Creatinine (mg/dL)	2.54 (per 1mg/dL)	0.84-7.69	0.099 (n.s)
pH	0.39 (per 0.1 unit)	0,19-0.79	0.009
Glycemia (mg/dL)	1.05 (per 10 mg/dL)	0.99-1.13	0.118 (n.s)
Lactate (mmol/L)	1.16 (per 1 mmol/L)	0.96-1.41	0.130 (n.s)
Shock Index	1.36 (per 0.1 unit)	1.13-1.63	<0.001

Table 12: Univariate logistic regression analysis of factors associated with the need for blood transfusion. For each variable, the odds ratio (OR) is reported for the unit increment indicated in parentheses, together with the corresponding 95% confidence interval (95% CI) and p-value. n.s. = not statistically significant (p ≥ 0.05).

8.2 Cats

A total of 106 traumatized cats were therefore included in the final study population.

Regarding breed distribution, the majority of cats were European breed (98/106), while purebred cats were represented by Maine Coon (2), Siberian (2), Persian (2), Thai (1) and Scottish Fold (1).

Regarding age distribution, most cats were young, with 67/106 (63%) aged 0-4 years. The median age of the cats was 4 years (range from 1 month to 16.5 years).

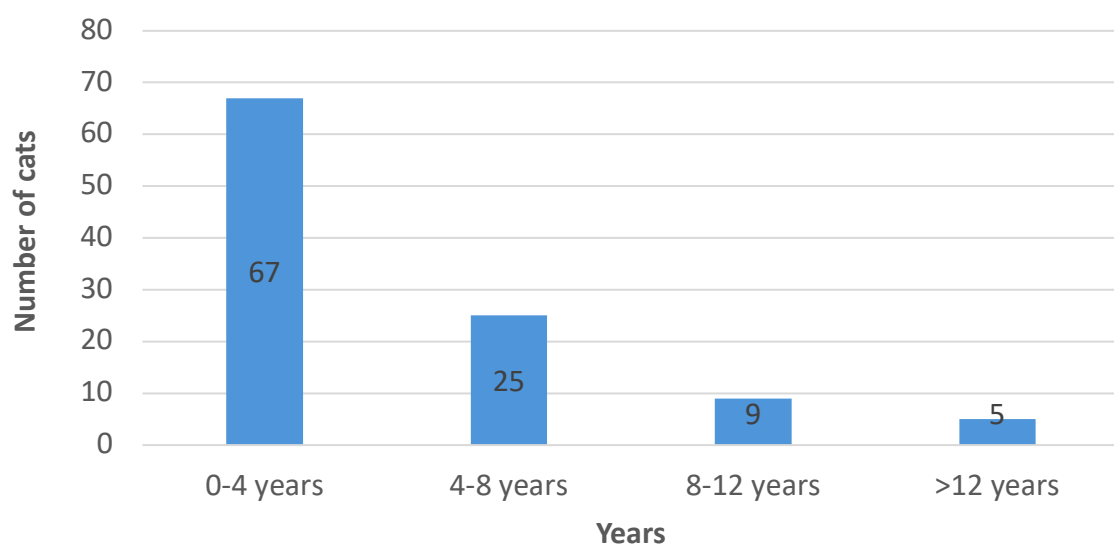


Figure 24: Distribution of age in the feline population.

In the study population 47/106 cats were female (44%), of which 30/47 were sterilised, and 59/106 cats were male (56%), of which 34/59 were castrated. Sterilised females were the oldest group (5.5 years), while intact males were the youngest (2.4 years). Mean body weight in cats varied slightly according to sex and reproductive status. Castrated males had the highest mean weight (5.12 kg), while the remaining groups showed more similar values. Unlike the pattern observed in the canine population, where castrated males showed a markedly higher mean

weight than the other groups, body weight in cats appeared more homogeneous. The median weight was 4.31 kg (range 0.4–7.8 kg).

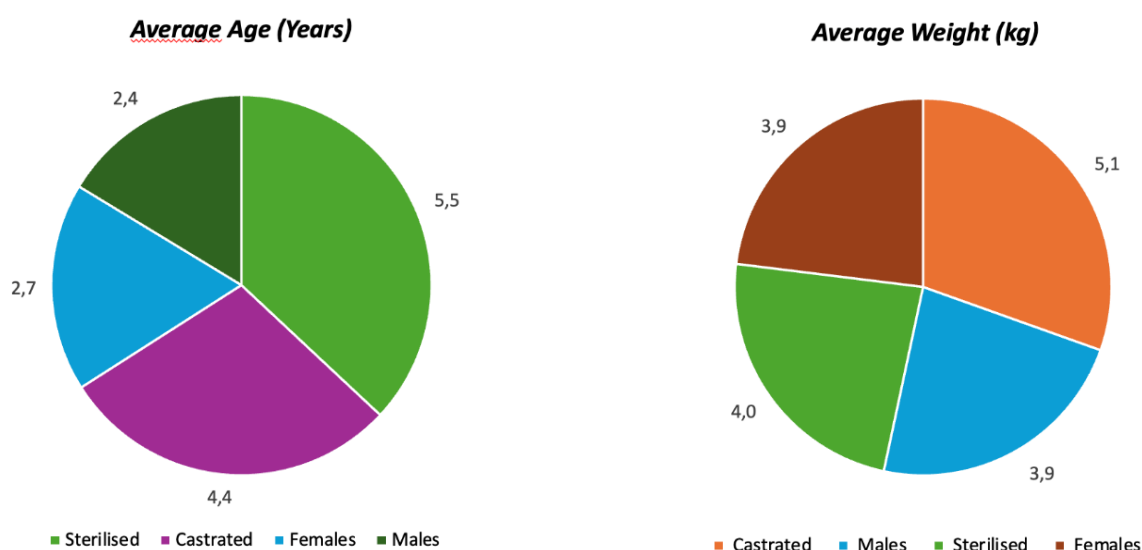


Figure 25: Mean age and mean weight according to sex and reproductive status.

Regarding trauma etiology, in the feline population motor vehicle accident was the most frequent trauma 37/106 (35%), followed by fall from height 28/106 (26%), unknown 21/106 (20%), bite injury 12/106 (11%) and crush injury 8/106 (8%).

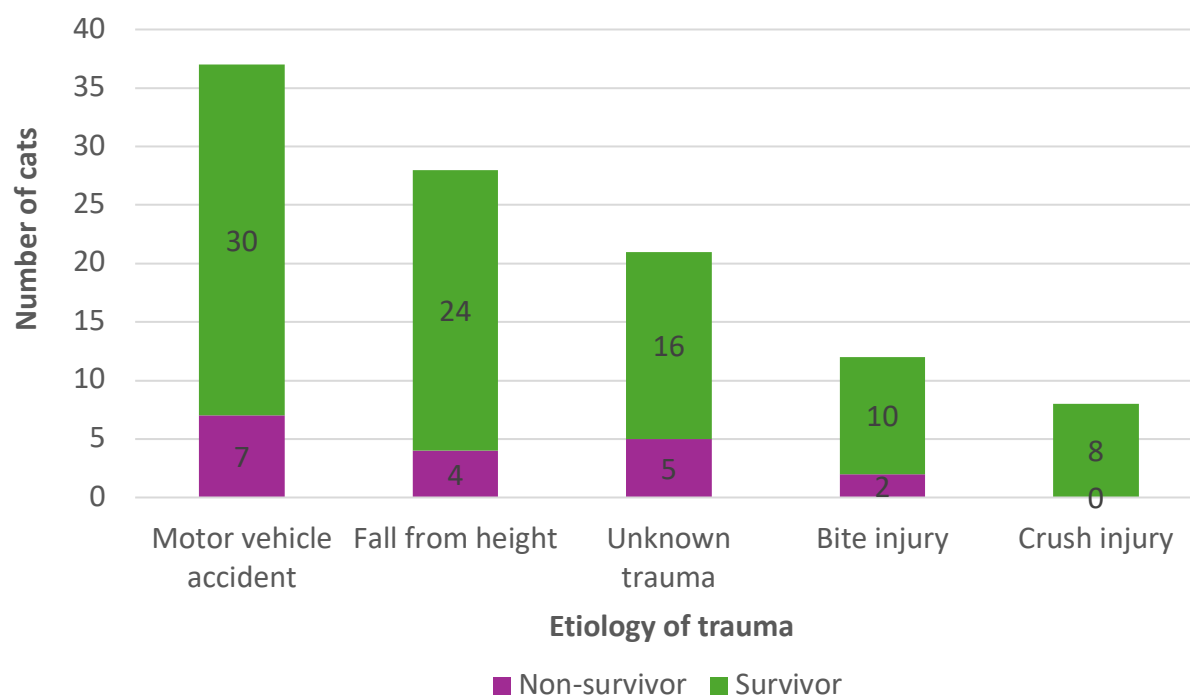


Figure 26: Distribution of trauma etiology and outcome (survivor/ non- survivor) in the feline population.

Among the anatomical trauma categories, orthopedic trauma was the most frequently observed, affecting 65/106 cats, followed by thoracic trauma 40/106 cats, abdominal trauma 15/106 cats, and head trauma 7/106 cats. Proportional mortality was highest for head trauma (3/7, 43%), followed by thoracic trauma (9/40, 23%), orthopedic trauma (10/65, 15%), while abdominal trauma showed the lowest proportional mortality (2/15, 13%). As in the canine population, these categories are not mutually exclusive, as some cats presented with trauma involving more than one anatomical region.

Of the 106 cats included in the study, 17 (16%) received a blood transfusion. The reason for transfusion was documented in 10 of these 17 cats; anemia or active blood loss was the most frequently reported indication, in 9 of these cases, while septic shock was reported in 1 case. Packed red blood cells were the most administered product (11/17 cats), followed by fresh frozen plasma (6/17). Mortality among transfused cats who received fresh frozen plasma was notably high (5/6, 83%).

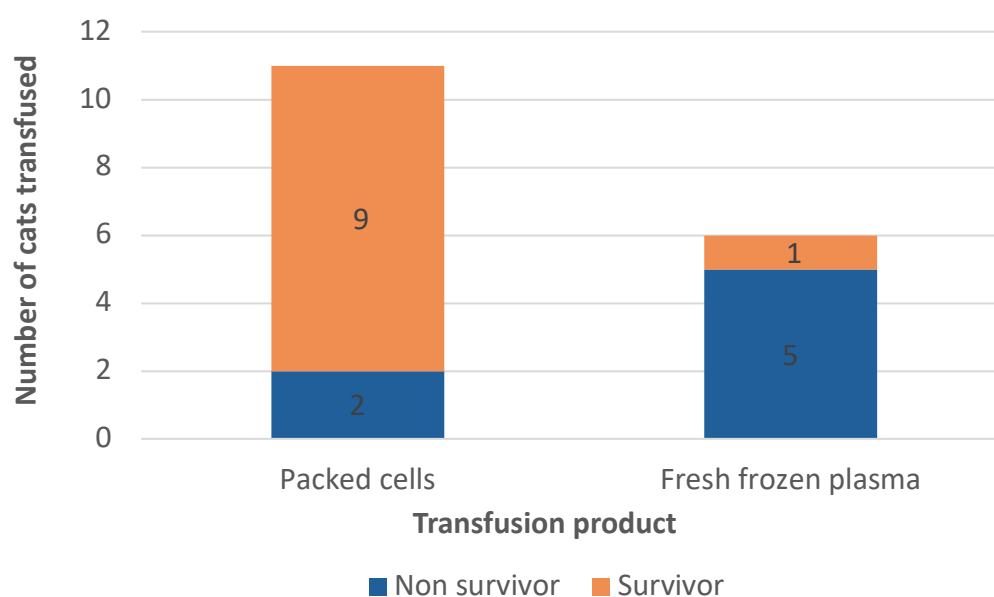


Figure 27: Blood products administered to transfused cats, by short-term outcome.

All transfused cats were monitored during transfusion following TRACS guidelines, and no transfusion reactions were recorded.

Blood typing for the AB system was performed in all 17 transfused cats. The majority were type A (16/17, 94%), while only 1 cat (6%) was type AB; no cats of type B were identified among the transfused population.

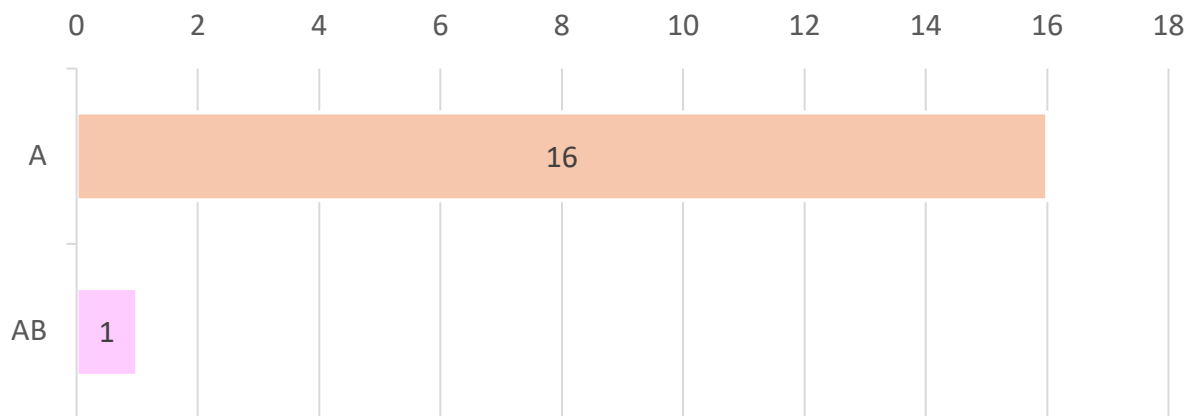


Figure 28: Distribution of AB blood types in transfused cats.

Among the transfused cats, the etiology of trauma varied: motor vehicle accident was the most frequent (7/17), followed by fall from height, bite injury, and unknown trauma (3/17 each), and crush injury (1/17). Mortality also varied by etiology: 2 of 7 cats (29%) with motor vehicle accident trauma died, compared with 2 of 3 cats (67%) with fall from height and bite injury each, and 1 of 3 cats (33%) with unknown trauma; the single cat with crush injury survived.

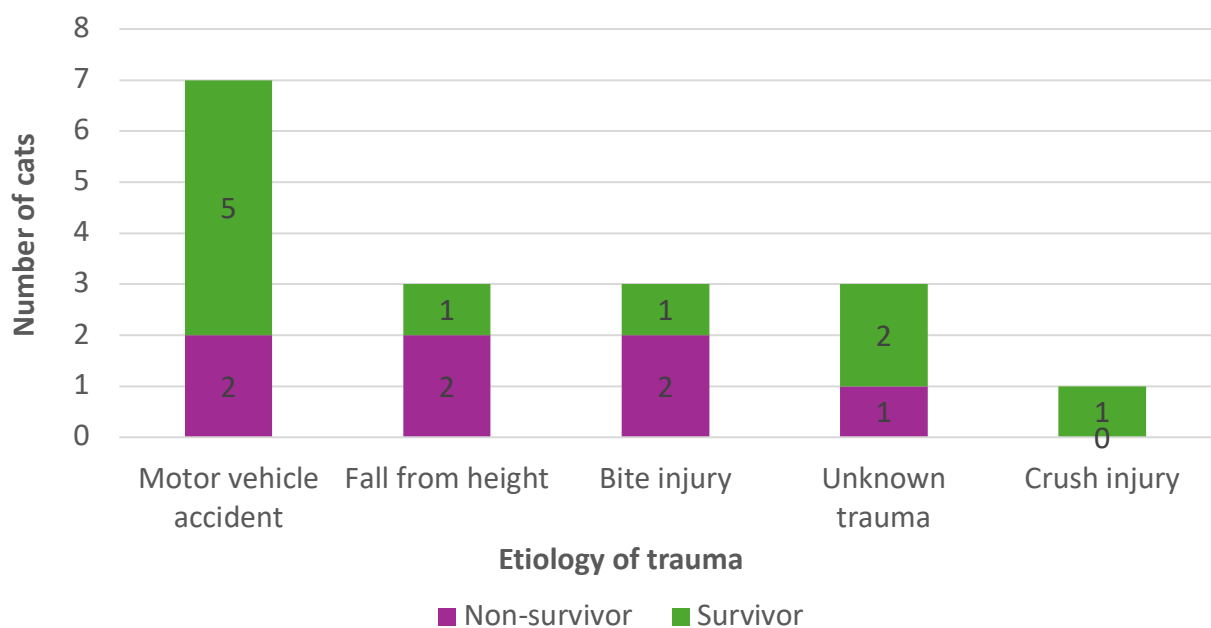


Figure 29: Etiology of trauma among transfused cats, by short-term outcome (survivor/ non-survivor).

A-FAST was performed in 55/106 cats (52%), of which 8 (15%) tested positive, all showing free abdominal fluid. Etiology among A-FAST positive cats included fall from height (6 cases), motor vehicle accident (1 case) and unknown (1 case). 3 of the 8 A-FAST positive cats died, all following fall from height trauma. 3 A-FAST positive cats received a blood transfusion: 2 with packed red blood cells and 1 with fresh frozen plasma; 2 of them died (one transfused with packed red blood cells and one with fresh frozen plasma).

T-FAST was performed in 55/106 cats (52%), of which 4 (7%) tested positive. Etiology among T-FAST positive cats included fall from height (3 cases) and unknown (1 case). One T-FAST positive cat died, following fall from height trauma; this was the same cat already reported among the A-FAST positive fatalities. 2 T-FAST positive cats received a blood transfusion: one with packed red blood cells and one with fresh frozen plasma; corresponding to the same two cats already described as transfused among the A-FAST positive population. These findings indicate that both transfused cats, as well as the fatal case, tested positive on both A-FAST and T-FAST.

Among the clinical-pathological and severity variables evaluated, four parameters showed a statistically significant difference between transfused and non-transfused cats. These variables are described individually in this section and presented as box plots in Figures 30-33.

Hematocrit values were available for 99 of the 106 cats (93%). Among these, 16 were transfused cats and 83 were non-transfused cats. Mean hematocrit was $26.38 \pm 7.44\%$ (range 10-35.1) in transfused cats, and $34.06 \pm 7.55\%$ (range 14.6-49.2) in non-transfused cats. Hematocrit was significantly lower in transfused cats (Welch's t-test, $p = 0.001$).

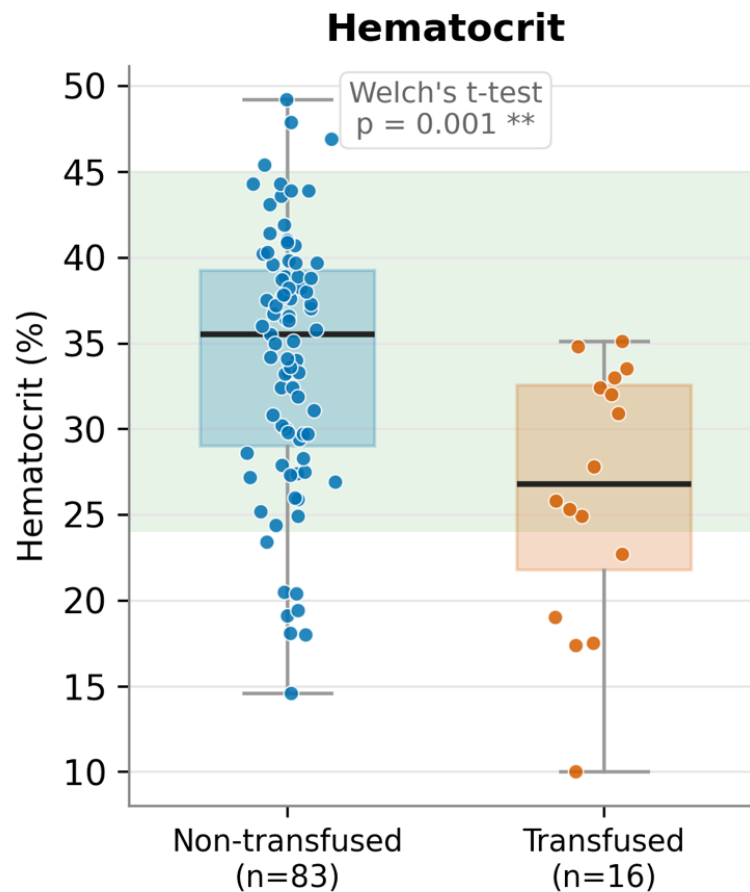


Figure 30: Box plot comparing hematocrit between non-transfused (blue, $n=83$) and transfused (orange, $n=16$) cats. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Welch's t-test was used for comparison ($p = 0.001$).

Total protein was available for 97 of the 106 cats (92%). Among these, 16 were transfused cats and 81 were non-transfused cats. The median total protein was 5.37 g/dL (range 4.61-7.95) in transfused cats, and 6.47 g/dL (range 4.61-7.95) in non-transfused cats. Total protein concentration was significantly lower in transfused cats (Mann-Whitney test, $p = 0.003$).

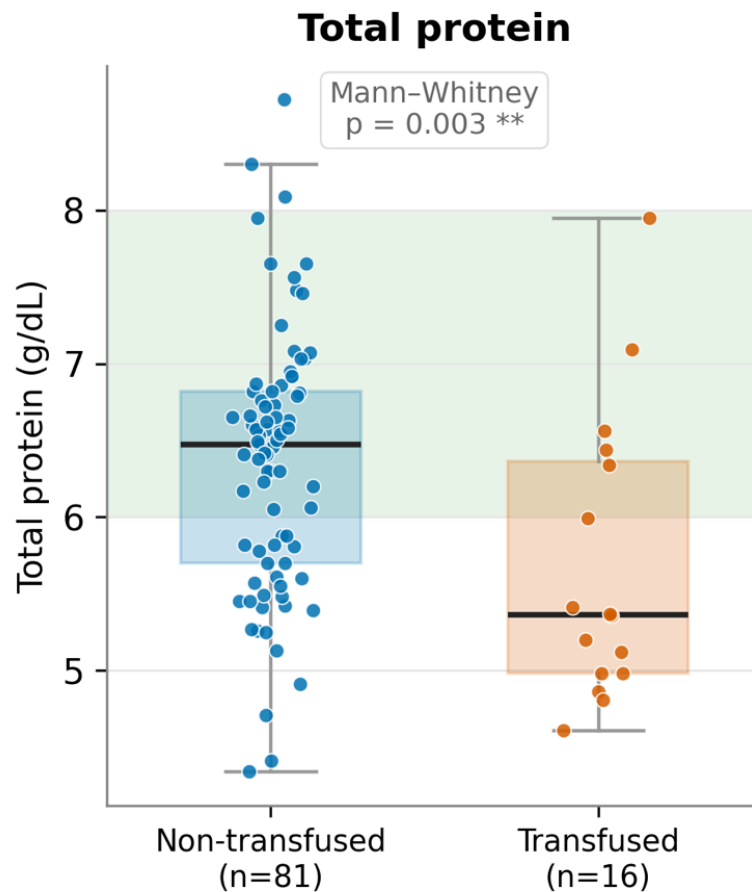


Figure 31: Box plot comparing total protein between non-transfused (blue, $n=81$) and transfused (orange, $n=16$) cats. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.003$).

Albumin was available for 96 of the 106 cats (91%). Among these, 16 were transfused cats and 80 were non-transfused cats. The median albumin was 2.47 g/dL (range 1.58-3.17) in transfused cats, and 3.1 g/dL (range 1.9-4.27) in non-transfused cats. Albumin concentration was significantly lower in transfused cats (Mann-Whitney test, $p < 0.001$)

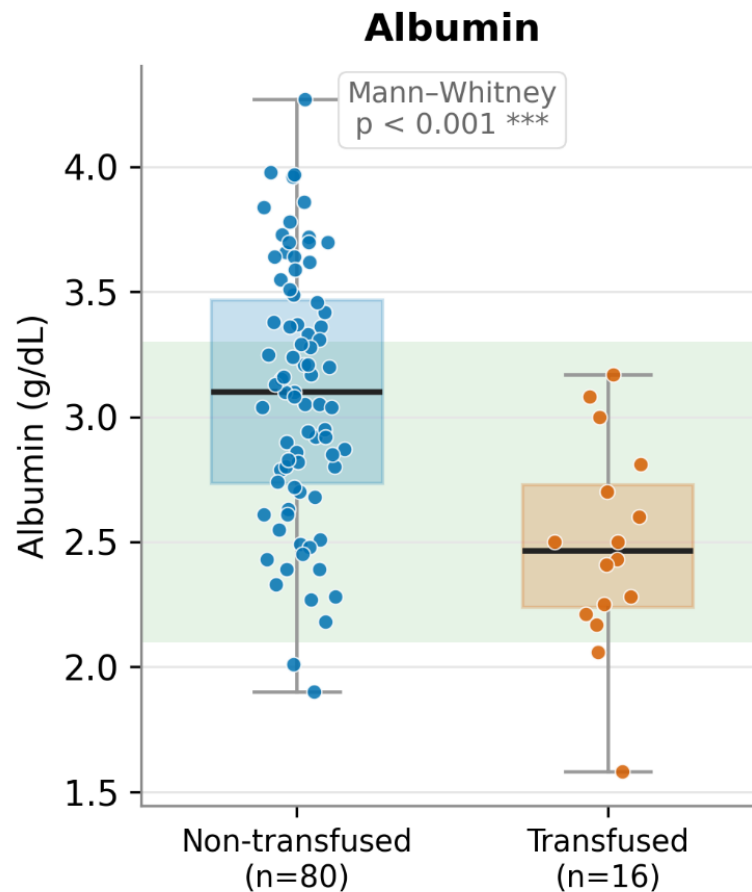


Figure 32: Box plot comparing albumin between non-transfused (blue, $n=80$) and transfused (orange, $n=16$) cats. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p < 0.001$).

Base excess (BE) was available for 93 of the 106 cats (88%). Among these, 16 were transfused cats and 77 were non-transfused cats. The median base excess was -9.15 mmol/L (range -15.9 to -4.4) in transfused cats, and -6.4 mmol/L (range -18.2 to -2.8) in non-transfused cats. Base excess was significantly more negative in transfused cats (Mann-Whitney test, $p = 0.006$).

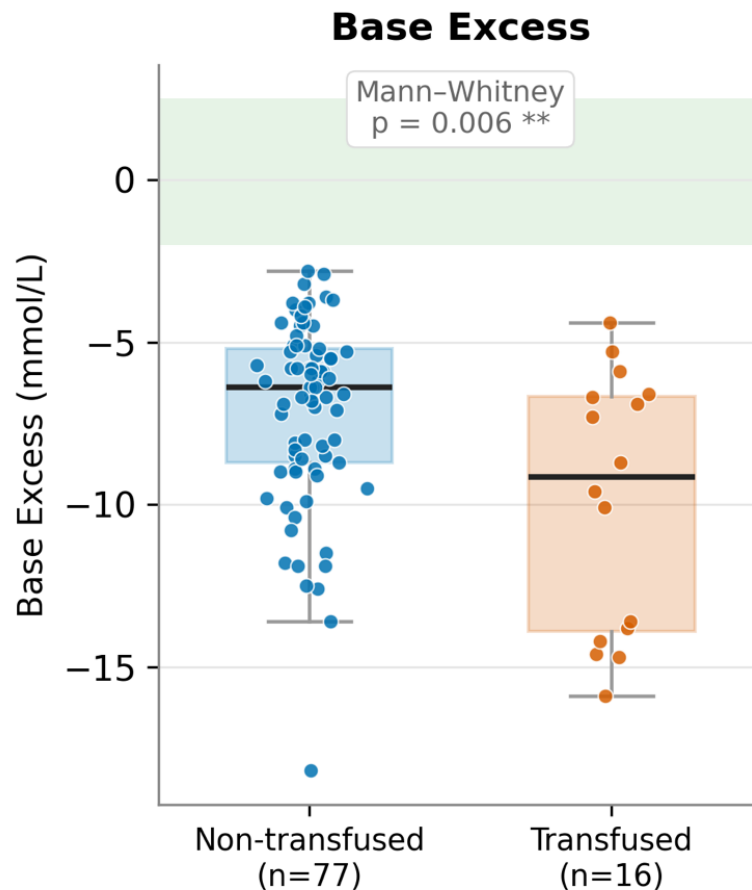


Figure 33: Box plot comparing base excess between non-transfused (blue, $n=77$) and transfused (orange, $n=16$) cats. The box represents the interquartile range (25th-75th percentile); the middle line represents the median; whiskers extend from the minimum to the maximum value, excluding outliers; individual dots represent single animals. The green band represents the reference interval for the parameter. Mann-Whitney test was used for comparison ($p = 0.006$).

The Shock Index (SI) was calculated for 74 of the 106 cats (70%). Among these, 10 cats died, of which 4 had a Shock Index greater than 1.5. 28 cats had a Shock Index greater than 1.5, of which 4 died. Among these 28 cats, only 3 received a blood transfusion (packed red blood cells), with Shock Index values of 1.87, 1.69, and 2.75. Overall, Shock Index did not differ significantly between transfused and non-transfused cats (Mann-Whitney test, $p = 0.830$).

No statistically significant differences were found between transfused and non-transfused cats for ALT ($p = 0.791$), creatinine ($p = 0.627$), pH ($p = 0.190$), glycemia ($p = 0.252$), lactate ($p = 0.376$), PT ($p = 0.717$), aPTT ($p = 0.402$), and Shock Index ($p = 0.830$). A summary of all clinical-pathological findings and severity scores, including both significant and non-significant variables, is provided in Table 13.

Variable	RI	Cats	Trasfused	Non-trasfused	P value
Hematocrit	24.0-45.0	32.82 $\pm$ 8.02	26.38 $\pm$ 7.44	34.06 $\pm$ 7.55	0.001
ALT (U/L)	32-87	210 (8-2836)	244 (40-2391)	190 (8-2836)	0.791
Total protein (g/dL)	6.0-8.0	6.41 (4.34-8.72)	5.37 (4.61-7.95)	6.47 (4.34-8.72)	0.003
Albumin (g/dL)	2.1-3.3	3.02 (1.58-4.27)	2.47 (1.58-3.17)	3.1 (1.9-4.27)	<0.001
Creatinine (mg/dL)	0.8-1.8	1.15 (0.48-3.63)	1.14 (0.75-3.63)	1.16 (0.48-3.15)	0.627
pH	7.27-7.46	7.29 (6.95-7.41)	7.25 (6.95-7.38)	7.29 (7.12-7.41)	0.190
Glycemia (mg/dL)	72-136	178 (68-463)	143 (98-398)	181 (68-463)	0.252
Base Excess (mmol/L)	-2 – +2.5	-6.7 (-18.2/-2.8)	-9.15 (-15.9/-4.4)	-6.4 (-18.2/-2.8)	0.006
Lactate (mmol/L)	0.0-1.5	2.6 (0.7-11.8)	2.5 (0.8-11.1)	2.6 (0.7-11.8)	0.376
PT	9-15	12.3 (7.5-18.8)	12.3 (11.1-18.6)	12.35 (7.5-18.8)	0.717
aPTT	9-17	15.1 (9.1-72)	15.6 (12.3-72)	15 (9.1-26)	0.402
Shock Index	-	1.39 (1-2.75)	1.46 (1.15-2.75)	1.38 (1-2.5)	0.830

Table 13: Clinical-pathological findings and severity scores in transfused (n=17) and non-transfused (n=89) cats. Data are reported as median (range), except for hematocrit, reported as mean $\pm$ standard deviation. P values were calculated using the Mann-Whitney U test for all variables, except hematocrit, for which Welch's t-test was used.

To further evaluate the predictive value of the four variables found to differ significantly between transfused and non-transfused cats, univariate logistic regression analysis was performed (Table 14). Hematocrit, total protein, albumin, and base excess were all confirmed as significant predictors of transfusion requirement.

Variable	Odds ratio	IC 95%	P value
<i>Hematocrit</i>	<i>0.88 (per 1%)</i>	<i>0.82-0.95</i>	<i>0.001</i>
<i>Total protein (g/dL)</i>	<i>0.39 (per 1g/dL)</i>	<i>0.19-0.79</i>	<i>0.009</i>
<i>Albumin (g/dL)</i>	<i>0.07 (per 1g/dL)</i>	<i>0.02-0.30</i>	<i><0.001</i>
<i>Base Excess (mmol/L)</i>	<i>0.78 (per 1 mmol/L)</i>	<i>0.66-0.92</i>	<i>0.004</i>

Table 14: Univariate logistic regression analysis of factors associated with the need for blood transfusion in cats. For each variable, the odds ratio (OR) is reported for the unit increment indicated in parentheses, together with the corresponding 95% confidence interval (95% CI) and p-value.

9. Discussion

This retrospective study is based on a population of 95 dogs and 106 cats admitted to the Ospedale Veterinario Universitario Didattico (OVUD) of the University of Parma with a diagnosis of trauma and at least one day of recovery, in a period between January 1st 2023 and June 30th 2026. The aim of this study was to describe the indications for transfusion practice in traumatized dogs and cats, and to evaluate whether laboratory parameters measured on admission could serve as early predictors of the need for blood transfusion, and whether these predictors differ between the two species.

The demographic parameters of our population are in keeping with those reported in the literature for traumatized dogs and cats. [100] No marked difference in sex distribution was observed in either species (males 55% in dogs and 56% in cats; females 45% in dogs and 44% in cats), and the age distribution reflected the two populations well, with a younger feline population (median age 4 years) than the canine one (median age 7.6 years).

When considering the outcome, 81 of 95 dogs (85%) and 88 of 106 cats (83%) survived to hospital discharge. These figures are in keeping with a recent large-scale multicenter trauma registry, which reported survival to discharge of 93.1% in dogs and 82.5% in cats. [100] Our feline survival was particularly close to that of the registry, whereas canine survival was somewhat lower: this might be explained by our inclusion criterion of hospitalization for at least one day, which selects for more severely affected animals, and by the referral caseload of a university teaching hospital.

Regarding the etiology of trauma, motor vehicle accident was the most frequent cause in both species, in agreement with its established role as a leading cause of trauma in dogs and cats. [8] Some species-specific differences, however, are worth noting. Fall from height was considerably more common in cats than in dogs (26% vs 14%), a finding consistent with the well-known feline high-rise syndrome, related to cats' access to elevated windows and balconies. [101] Conversely, bite injury was far more frequent in dogs than in cats (34% vs 11%), possibly reflecting their greater interaction with other dogs during outdoor activity. Gunshot trauma was observed only in the canine population (1/95 cases), and was attributable to a single hunting episode, which may reflect a greater exposure of dogs to this type of trauma.

Of our population, 14 dogs (15%) and 17 cats (16%) received a blood transfusion. Interestingly, the two species differed in the product administered: in dogs fresh frozen plasma was almost the only product used (14/14), whereas in cats packed red blood cells prevailed (11/17). It might be tempting to interpret this as coagulopathy being the main indication in dogs and anemia in cats; however, PT and aPTT did not differ between transfused and non-transfused dogs ($p=0.444$ and $p=0.389$) and remained within the reference interval, which argues against overt coagulopathy as the main driver. The reason for transfusion, when documented in the medical records (10/14 dogs and 10/17 cats), highlighted these differences: in cats, anemia or active blood loss was by far the most frequently reported indication (9/10 documented cases), consistent with the predominant use of packed red blood cells. In dogs, however, septic shock was the most frequently reported indication (7/10 documented cases), with suspected or confirmed traumatic coagulopathy reported in only 2 cases. This suggests that the near-exclusive use of plasma in dogs may reflect the management of septic-shock-associated coagulopathy, rather than coagulopathy directly attributable to the traumatic event itself; it also departs from the red-cell or whole-blood-based approach that current damage-control resuscitation strategies would favor in actively bleeding patients. In conclusion, these findings should be read as a picture of real-world practice at a single referral center, and not as evidence of a specific trauma-induced coagulopathic phenotype.

An interesting point concerns pretransfusion blood typing. In our study, DEA 1 typing was known before transfusion in only half of the transfused dogs, whereas AB typing was performed in all transfused cats. This discrepancy reflects the historical assumption that pretransfusion testing is less critical in dogs, which lack clinically significant naturally occurring alloantibodies against DEA 1 [43], in contrast to cats, in which naturally occurring anti-A and anti-B alloantibodies can trigger a hemolytic reaction even on the first transfusion. [66] This assumption, however, has been increasingly challenged: recent studies report immunologic incompatibility in 17% of transfusion-naïve dogs [84] and the development of alloantibodies as early as one day after a first transfusion. [85] Our findings therefore support the recommendation to type and crossmatch before every canine transfusion, regardless of transfusion history.

Among our transfused cats, type A largely predominated (16/17, 94%), with a single type AB cat and no type B cats. This distribution is in keeping with the literature, which describes type A as the predominant blood type in European domestic shorthair cats. [76] Since all cats were typed

before transfusion, and no type B cats were identified, the risk of AB-incompatibility reactions was likely minimized in this population. [66]

No transfusion reactions were recorded in either species. This result, however, must be interpreted with caution given the small number of transfused animals: reported incidences of acute transfusion reactions range from 4% to 9% in dogs and up to 16% in cats, [89, 90] so that the absence of observed reactions in this study does not necessarily reflect a true absence of risk.

Mortality among transfused animals was considerably higher than in the overall population, reaching 43% in dogs (6/14) and 41% in cats (7/17). This is not surprising, as the need for transfusion usually identifies the most severely injured patients. Mortality was particularly high among cats that received plasma (5/6, 83%) compared with those that received packed red blood cells (2/9, 22%), and a similar excess among plasma recipients was seen in dogs. This should not be read as a harmful effect of plasma itself: more likely, it reflects confounding by indications, since the most unstable animals were also those most likely to receive plasma.

Point-of-care ultrasonography also provided useful information. Among transfused dogs, one was A-FAST positive with free abdominal fluid and subsequently died – the only fatality among A-FAST positive dogs. This is consistent with the role of free abdominal fluid as one of the informative components of the TASH score, previously associated with increased transfusion requirement in traumatized dogs. [55] Among transfused cats, 3/17 were A-FAST positive and 2/17 T-FAST positive; notably, the same two cats tested positive on both examinations, and one of them died, suggesting that combined A-FAST and T-FAST positivity may identify a particularly high-risk subgroup.

We then evaluated several clinical-pathological parameters in relation to transfusion requirement, including hematocrit, total protein, albumin, creatinine, ALT, pH, glycemia, base excess, lactate, PT, and aPTT. Seven of these differed significantly between transfused and non-transfused dogs, and four in cats. The most relevant are discussed individually below.

Total protein and albumin are among the most rapidly and widely available parameters on admission, and in our population they were the most consistent predictors of transfusion requirement, being significant in both species and on both univariate and logistic analysis (total protein OR 0.35 [0.16–0.75] in dogs and 0.39 [0.19–0.79] in cats; albumin OR 0.06, [0.01–0.38] in

dogs and 0.07, [0.02–0.30] in cats). This is in keeping with the literature, which identifies admission total protein as a predictor of red blood cell transfusion in dogs with hemoabdomen. [102] In fact, the result can be explained by the pathophysiology of acute whole-blood loss: since plasma proteins are lost together with erythrocytes, total solids and albumin decrease early, whereas the hematocrit may be transiently preserved. In conclusion, admission hypoproteinemia was the single most reliable marker of transfusion requirement across both species.

Hematocrit behaved very differently in the two species, and this is one of the most interesting findings of our study. In dogs, admission hematocrit did not differ between transfused and non-transfused animals ($p=0.853$), whereas in cats it was the single strongest predictor of transfusion (OR 0.88 per 1% [0.82–0.95]). This divergence may be explained by the same mechanism described above. Dogs possess a large and contractile spleen: after acute hemorrhage, splenic contraction transiently maintains — or even increases — the circulating red cell mass, so that the admission hematocrit may mask blood loss, while plasma proteins, which are not stored in the same way, fall earlier and keep their discriminative value. In cats, in which this splenic reserve is more limited, the hematocrit falls earlier after hemorrhage and becomes a more reliable admission marker. In conclusion, our data reinforce the well-known recommendation to interpret hematocrit and total protein together in the acutely bleeding patient, rather than relying on hematocrit alone. [11]

The Shock Index (SI), defined as the ratio between heart rate and systolic blood pressure, is a simple bedside marker of circulatory compromise. In our study it showed the opposite species pattern to hematocrit: it was the strongest predictor of transfusion in dogs (OR 1.36 per 0.1-unit increase [1.13–1.63]) but was not associated with transfusion in cats ($p=0.830$). Taken together with the hematocrit findings, this suggests that hemodynamic instability was the more prominent driver of transfusion in dogs, whereas anemia was more central in cats. The feline SI, however, should be interpreted with caution, given the higher physiological heart rate of cats and the lack of validated feline reference thresholds.

Venous blood pH and base excess reflect the metabolic consequences of hypoperfusion. Venous blood pH was a significant predictor of transfusion in dogs (OR 0.39 per 0.1 unit [0.19–0.79]), consistent with metabolic acidosis as a marker of shock severity. Base excess, on the other hand, was a significant predictor in cats (OR 0.78 per 1 mmol/L [0.66–0.92]) but not in dogs. This last result is somewhat surprising, as it contrasts with previous work identifying admission base

excess as a predictor of transfusion in dogs with blunt trauma. [17] It should be noted, however, that in our cohort base excess was still more negative in transfused than in non-transfused dogs (median -5.7 vs -4.1 mmol/L), and the lack of significance ($p=0.109$) may simply reflect the small number of transfused animals; a difference in outcome definition — any blood product here versus red cell transfusion specifically in Stillion and Fletcher [17] — may also contribute.

Creatinine, glycemia, and lactate differed significantly between transfused and non-transfused dogs on univariate comparison, but none were confirmed as independent predictors on logistic regression. This does not diminish their clinical value: elevated creatinine, hyperglycemia and hyperlactatemia remain recognized markers of tissue hypoperfusion and physiological derangement in trauma patients, and their loss of significance most likely reflects the limited number of transfused animals rather than a true absence of association.

Our study has several limitations that must be considered when interpreting the results. First of all, it is retrospective and based on a single referral teaching hospital, which limits the generalizability of the findings. Second — and probably most important for a study of transfusion predictors — the decision to transfuse was not based on a standardized protocol but left to clinician judgment; the outcome we investigated is therefore partly subjective and institution-dependent, and our predictors describe local transfusion practice more than a physiologically defined transfusion need. Another limitation was the small number of transfused animals (14 dogs and 17 cats), which reduced the statistical power to detect smaller associations, such as creatinine, glycemia and lactate in dogs, and did not allow a multivariable model to be built, so that confounding among predictors cannot be excluded. Furthermore, not all animals underwent the complete diagnostic panel — for example, the Shock Index could be calculated in only 82 of 95 dogs and 74 of 106 cats — which may have introduced selection bias, and the trauma categories were not mutually exclusive, which prevents attribution of transfusion requirement to a single anatomical region. Finally, established composite scores such as ATT and APPLE were not calculated: their prospective evaluation alongside admission laboratory parameters would be a logical next step. A prospective multicenter study with standardized transfusion criteria and a larger number of animals would be necessary to confirm our results.

10. Conclusion

This study helps to describe the clinical-pathological predictors of transfusion requirement in a single-center population of traumatized dogs and cats. In dogs four parameters were confirmed as significant predictors of transfusion requirement: Shock Index, total protein, albumin, and venous blood pH. In cats four parameters were also considered significant: hematocrit, total protein, albumin, and base excess.

Total protein and albumin were the only predictors consistent across both species, confirming hypoproteinemia as a key early marker for transfusion. Markers of tissue hypoperfusion also emerged as significant predictors, although in a species-specific manner: venous blood pH in dogs and base excess in cats. The remaining parameters showed divergent predictive value between dogs and cats.

These parameters are rapidly obtainable at hospital admission. They represent a valuable tool to complement standard clinical evaluation and support early recognition of patients likely to require transfusion.

These findings should be considered preliminary, given the retrospective, single-center design and the limited number of transfused animals. A prospective, multicenter study would be needed to confirm these results.

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