

RETROSPECTIVE EVALUATION OF THE INDICATIONS, COMPLICATIONS, AND OUTCOMES OF EXTRACORPOREAL THERAPIES IN COMPANION ANIMALS IN A VETERINARY TEACHING HOSPITAL

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Abstract

Objective: To describe the indications, complications, and outcomes of companion animals treated with extracorporeal therapy (ECT).

Design: Retrospective case series from November 2023 to December 2024, with a 1-month follow-up.

Setting: Single-center study at a veterinary university teaching hospital.

Animals: Forty-one client-owned animals (37 dogs, four cats) treated with ECT for endogenous substance accumulation (ESA [$n = 28$], including acute kidney injury [AKI; $n = 27$] or post-attenuation neurologic signs [PANS; $n = 1$]), immune-mediated disease (IMD; $n = 3$), or intoxication ($n = 10$).

Measurements and Main Results: Data collected included signalment, indication, ECT type (hemodialysis [HD], hemoperfusion [HP], or therapeutic plasma exchange [TPE]), complications, and outcome. A total of 103 ECT sessions were performed. Session complications were frequent (HD: 27%, HP: 71%, TPE: 64%), most commonly circuit clotting (15/103), hypocalcemia (10/103), bleeding (9/103), and hemodynamic instability (9/103); none were fatal. Assessment of specific complication risks by ECT type was limited by sample size, but the complication rate of HD was lower compared with other modalities ($p = 0.012$). Overall, 25 of 41 animals were discharged, and 20 of 25 survived 1 month. Survival in dogs differed by indication: 100% (10/10) for intoxication, 57% (13/23) for AKI, and 33% (1/3) for IMD ($p = 0.006$). Among dogs with AKI, those with probable or confirmed leptospirosis had higher 1-month survival (9/19) compared with other causes of AKI (1/4) ($p = 0.014$).

Conclusions: ECT is associated with a moderate to high complication rate, but most complications were mild and transient. Intoxicated patients receiving ECT had an excellent prognosis, while dogs with AKI and confirmed or probable leptospirosis showed better survival than those dogs with AKI unlikely to be due to leptospirosis.

Abbreviations: AKI, acute kidney injury; aPTT, activated partial thromboplastin time; ECT, extracorporeal therapy; ESA, endogenous substance accumulation; HD, hemodialysis; HP, hemoperfusion; IMD, immune-mediated disease; IMHA, immune mediated hemolytic anemia; NSAID, nonsteroidal anti-inflammatory drug; PANS, post-attenuation neurologic signs; PCR, polymerase chain reaction; TPE, therapeutic plasma exchange.

Results of this study were presented as a poster during the 2025 European Veterinary Emergency and Critical Care Congress.

1. Introduction

Extracorporeal therapies (ECTs) have been described for the treatment of endogenous substance accumulation (ESA), such as nitrogenous wastes in cases of acute kidney injury (AKI) [1, 2], for immune system modulation in immune-mediated diseases (IMDs) [3–7], or for blood purification in cases of severe intoxication [8–10]. The three main modalities of ECT for blood purification described in veterinary medicine are hemodialysis (HD), hemoperfusion (HP), and therapeutic plasma exchange (TPE). The selection of a specific ECT modality depends on the physicochemical properties of the target substance, particularly how the toxin or endogenous compound behaves in circulation [8]. Substances effectively removed by HD are typically hydrophilic and have a low molecular weight (< 1000 Da), a low protein-binding percentage (< 80%), and a low volume of distribution (< 1 L/kg). In HP, a sorbent is used to selectively or nonselectively adsorb circulating substances. The process is effective at removing molecules with a high protein-binding capacity (> 80%) or a large molecular weight (from 500 to 45,000 Da). Finally, TPE is a form of apheresis therapy in which plasma is separated from the cellular components of blood and replaced. In centrifugal TPE, the patient's plasma is returned after targeted substances are removed, whereas in membrane-based TPE, the removed plasma is discarded and replaced with donor plasma. TPE is usually used for molecules with a high protein-binding capacity (> 95%) and a large molecular weight (> 50,000 Da) [8].

The most common application of HD in veterinary medicine is for severe AKI that is unresponsive to conventional medical management. HD is indicated in patients with severe or progressive azotemia, refractory hyperkalemia, life-threatening fluid overload, severe acid–base imbalances, or uncontrolled clinical signs of uremia that do not respond to traditional treatment [1]. HP is primarily described in veterinary literature for the treatment of severe intoxications [8], such as with nonsteroidal anti-inflammatory drugs (NSAIDs) [11–13], metaldehyde [14], and methotrexate [15]. TPE was initially described in dogs for the management of NSAID intoxications [16, 17], but it is gaining interest for the treatment of refractory IMD, such as immune-mediated hematologic disorders (immune-mediated hemolytic anemia [IMHA] [3, 7] and thrombocytopenia [5, 7]) and neuromuscular disorders (polyradiculoneuritis [6] and myasthenia gravis [4]). Favorable outcomes with clinical improvement or remission have been described in case reports and case series [3, 5, 7].

Reported complication rates of ECT in companion animals range between 18% and 79% [1, 7, 9, 18–21], with most events being mild and not associated with mortality. The most common complications

of HD are hypovolemia, bleeding due to systemic heparinization, and circuit clotting [1, 18–21]. During HP, mild hypotension and thrombocytopenia have been reported [9]. External bleeding at the catheter insertion site due to systemic heparinization, circuit clotting, and hypotension resulting from transient decreased oncotic pressure are complications observed in TPE [7, 9]. Moreover, the administration of exogenous plasma with membrane-based TPE can be further associated with transfusion-related reactions ranging from mild reactions such as urticaria and transient hyperthermia, to systemic anaphylactic reactions, as well as hypocalcemia due to citrate overload [7, 22].

The objective of the current study was to describe the patients' characteristics, medical indications and techniques used for ECT, degree of urgency of the procedure, complications per ECT modality, and patient outcomes. We hypothesized that survival would be higher in cases of intoxication compared with other indications; that survival would be higher in leptospirosis-related AKI compared with other causes of AKI; and that HD would be associated with fewer complications than TPE or HP.

2. Materials and Methods

2.1 ANIMAL-FOCUSED DATA COLLECTION

Medical records of dogs and cats treated with ECT at the veterinary teaching hospital of the University of Liège in Belgium, from November 2023 to December 2024, were retrospectively reviewed. The collected information included species, breed, sex, age, body weight, final diagnosis, and outcome. Outcomes were categorized as follows: survival, euthanasia, or death before hospital discharge; and alive, euthanized, or died 1 month after discharge.

2.2 GROUPS

Patients were classified into three ECT indication groups: ESA, IMD, and intoxication. Animals in the ESA group were classified as those presenting with AKI (as defined in the International Renal Interest Society consensus [2]) and animals suffering from post-attenuation neurologic signs (PANS), defined as the occurrence of severe neurologic signs after elective surgery for portosystemic shunt attenuation, without hypoglycemia or electrolyte disturbance [23]. Animals with AKI were further classified into two categories based on their likelihood of leptospirosis, according to the updated American College of Veterinary Internal Medicine consensus definition [24]: confirmed or probable leptospirosis, and unlikely leptospirosis. AKI group 1 included dogs that fulfilled the clinical criteria (systemic illness within the past 2 weeks, with or without additional gastrointestinal, pulmonary, ocular, renal, or hemorrhagic signs) together with at least two supportive clinicopathologic abnormalities (e.g., neutrophilic leukocytosis, thrombocytopenia, biochemical evidence of AKI or cholestatic hepatopathy, glucosuria with normoglycemia, active urine sediment, imaging findings consistent with leptospirosis). In addition, dogs in this group may have had a positive polymerase chain reaction (PCR) result or no alternative strongly suspected cause (e.g., recent NSAID administration) that could explain the clinical presentation. AKI group 2 comprised dogs for which leptospirosis was considered unlikely. These animals either failed to

meet the combination of clinical, clinicopathologic, and laboratory criteria described above or had alternative diagnoses that better explained their clinical presentation and laboratory findings.

The IMD group comprised dogs with IMHA, diagnosed based on at least one sign of hemolysis and one indicator of immune-mediated RBC destruction, in the absence of another cause of anemia, as per the American College of Veterinary Internal Medicine consensus [25]. Dogs with severe polymyositis, defined by muscle weakness combined with markedly increased plasma creatine kinase and myoglobinuria without identified infectious or metabolic cause, were also included. The intoxication group was composed of patients treated for evidence or clinical suspicion of drug overdose or toxin ingestion.

Table 1 | Definitions of therapeutic targets for extracorporeal therapies.

Therapeutic target	Definition
Azotemia	Plasmatic creatinine > 880 $\mu\text{mol/L}$ (severe) or increasing despite medical treatment in hydrated patients (progressive)
Hyperkalemia	Plasmatic potassium > 5.5 mmol/L
Oliguria/anuria	Urine output < 1 mL/kg/h (oliguria) or < 0.2 mL/kg/h (anuria) in hydrated patients
Acidemia	Venous pH < 7.35
Fluid over-load/overhydration	Combination of clinical signs, such as peripheral edema and point-of-care ultrasonography findings, including effusion, gallbladder edema, and cardiac or caudal vena cava signs of hypervolemia or congestion
Hyperbilirubinemia	Plasmatic bilirubin > 100 $\mu\text{mol/L}$

2.3 THERAPY-FOCUSED (ECT SESSIONS) DATA COLLECTION

For each extracorporeal session in each patient, a treatment file was available that listed the ECT technique applied (HD, HP, or TPE) and session number, technical aspects (blood circuit, hemofilter, or cartridge used), therapeutic targets, complications, as well as the degree of urgency.

Therapeutic targets were severe or progressive azotemia, hyperkalemia, acidemia, oliguria/anuria, fluid overload/overhydration, severe hyperbilirubinemia (all defined in **Table 1**) or suspected intoxication, evidence of toxic ingestion/ drug overdose, antibody removal, or PANS.

Similarly, complications observed during treatment were recorded on the treatment sheet. These complications were categorized into vascular access-related and treatment-related events, and each category was analyzed separately. To this end, vascular access sites were routinely inspected at the beginning of each session for signs of inflammation or hemorrhage at the insertion site, obstruction, or leakage. Animals were routinely monitored throughout the procedure, including continuous ECG, perfusion parameters, and systolic blood pressure (measured by Doppler, oscillometry, or invasive methods, depending on the case).

The degree of urgency was defined as a binary variable (yes/no), corresponding to the initiation of ECT in response to a life-threatening condition requiring immediate intervention, irrespective of time of day, when clinical deterioration was considered imminent without treatment.

2.4 ECT MODALITIES

A continuous platform¹ or an intermittent platform² connected to a water purification device³ was used for HD, depending on the animal's body weight and treatment aims, at the attending clinician's discretion.

A veterinary HP device⁴, using the manufacturer's blood line and pure carbon-filled cartridge⁵, was used to perform HP. A TPE circuit⁶ on the continuous platform was used to perform membrane-based TPE. In dogs, plasma was replaced with at least 50% of canine fresh frozen plasma, and the remaining volume was replaced with balanced isotonic crystalloids and synthetic colloids⁷ (dose range: 5%–10% of total exchanged volume) or 20% human albumin solution⁸ (dose range: 1–2 g/kg), depending on the animal's condition.

Anticoagulation was achieved either with systemic heparinization or with regional citrate anticoagulation. Systemic heparinization consisted of an intravenous bolus of unfractionated heparin before treatment, followed by a constant rate infusion adjusted to maintain the activated partial thromboplastin time (aPTT⁹) between 150 and 200 s for HD and between 200 and 250 s for HP and TPE. Regional citrate anticoagulation was performed according to a previously described protocol [26]. In cases where systemic heparinization was contraindicated and regional citrate anticoagulation was unavailable, treatments were conducted with low heparinization (constant rate infusion of unfractionated heparin at 12 U/kg/h, without bolus) or without anticoagulation.

All treatment prescriptions were designed following International Renal Interest Society consensus guidelines [1] for HD and guidelines provided by experts in the field for HP and TPE.

2.5 STATISTICAL ANALYSIS

Patient characteristics were descriptively summarized, with qualitative and discrete variables presented using frequency tables and quantitative variables summarized using standard descriptive statistics. Cats were not included in the comparative statistical analysis. The normality of quantitative variables was evaluated numerically, graphically, and using the Shapiro–Wilk test. Survival outcomes were compared by indication for ECT (AKI, IMD, intoxications) using Fisher's exact test; for logical reasons, the ESA group was restricted to AKI cases, excluding the single dog with PANS. The association between outcome and AKI group 1 and AKI group 2 was also tested using Fisher's exact test. The relationship between sex and outcome was assessed with Fisher's exact test, while age and body weight were compared between

survivors and nonsurvivors using Kruskal–Wallis tests. The association between the type of machine used and the degree of urgency was assessed using Fisher's exact test, while the relationship between body weight and the type of machine was analyzed using the Mann–Whitney U -test. Associations between the occurrence of complications and ECT modality, or urgency of treatment, were evaluated using Fisher's exact test. The relationship between body weight and the occurrence of complications was tested with the Mann–Whitney U -test. For all analyses, the confidence level was set at 95% ($p < 0.05$). Statistical analyses were performed using commercially available software¹⁰.

3. Results

3.1 CASE INCLUSION AND DEMOGRAPHIC DATA

A total of 41 animals, 37 dogs and four cats, were included in the study. The median age of dogs was 3.0 years (range: 0.3–8 years), and the median body weight was 19.8 kg (range: 2.7–45 kg). Most dogs were male (59%), and most dogs were neutered (57%). The most frequent canine breeds were cross-breed (7/37) and Labrador Retriever (7/37), followed by Australian Shepherd, Cocker Spaniel, and American Staffordshire Terrier (3 each). Cats had a median age of 6.9 years (range: 0.7–12 years) and a median body weight of 4.6 kg (range: 3.0–6 kg). Feline breeds were domestic shorthair (2/4), Bengal (1/4), and British Shorthair (1/4). Three cats were male, and one was female; all cats were neutered.

3.2 FINAL DIAGNOSIS AND ASSOCIATED ECT MODALITIES

Among the 41 animals included in the current study, 28 (24 dogs and four cats) underwent ECT for ESA, including 23 dogs and four cats for AKI and one dog for PANS after elective portosystemic shunt surgery. Ten dogs underwent ECT for intoxication and three dogs for IMD. **Figures 1 and 2** show the distribution of cases, indications, and applied ECTs.

Of the 23 dogs with AKI, 19 had confirmed or probable leptospirosis (AKI group 1). Among the dogs in AKI group 1, eight of 19 had a positive PCR result, four had a negative PCR result (all four dogs had received prior antimicrobial treatment), and seven dogs had no PCR performed due to the inability to collect urine samples upon admission because of anuria. Among the four dogs in AKI group 2, the etiology of AKI was unknown in three, and glomerulonephritis was the cause of AKI in one. In cats with AKI, the underlying cause was unknown in two cases—one cat presented with bilateral ureteral obstruction, and the final cat had unilateral ureteral obstruction with concurrent chronic kidney disease.

All patients with AKI underwent HD. Among the 19 dogs in AKI group 1 (confirmed or probable leptospirosis), eight underwent TPE in addition to HD for antibody removal due to leptospirosis-induced pulmonary hemorrhage, and two were treated additionally with HP in series due to severe hyperbilirubinemia and concurrent neurologic signs.

Three dogs underwent TPE for IMD, two with IMHA and one with polymyositis. The dog with PANS also underwent TPE.

Finally, 10 dogs underwent ECT for intoxication. Causes (and applied ECT technique) included acute methemoglobinemia (HD: $n=1$; HD + HP in series: $n=1$, HP: $n=1$), chocolate intoxication (HD: $n=2$), NSAID (HP: $n=1$), phenobarbital overdose (HP: $n=1$), paracetamol (acetaminophen) overdose (HD: $n=1$), suspected mycotoxin intoxication (HD + HP: $n=1$), and ethylene glycol ingestion (HD: $n=1$) (**Table 2**).

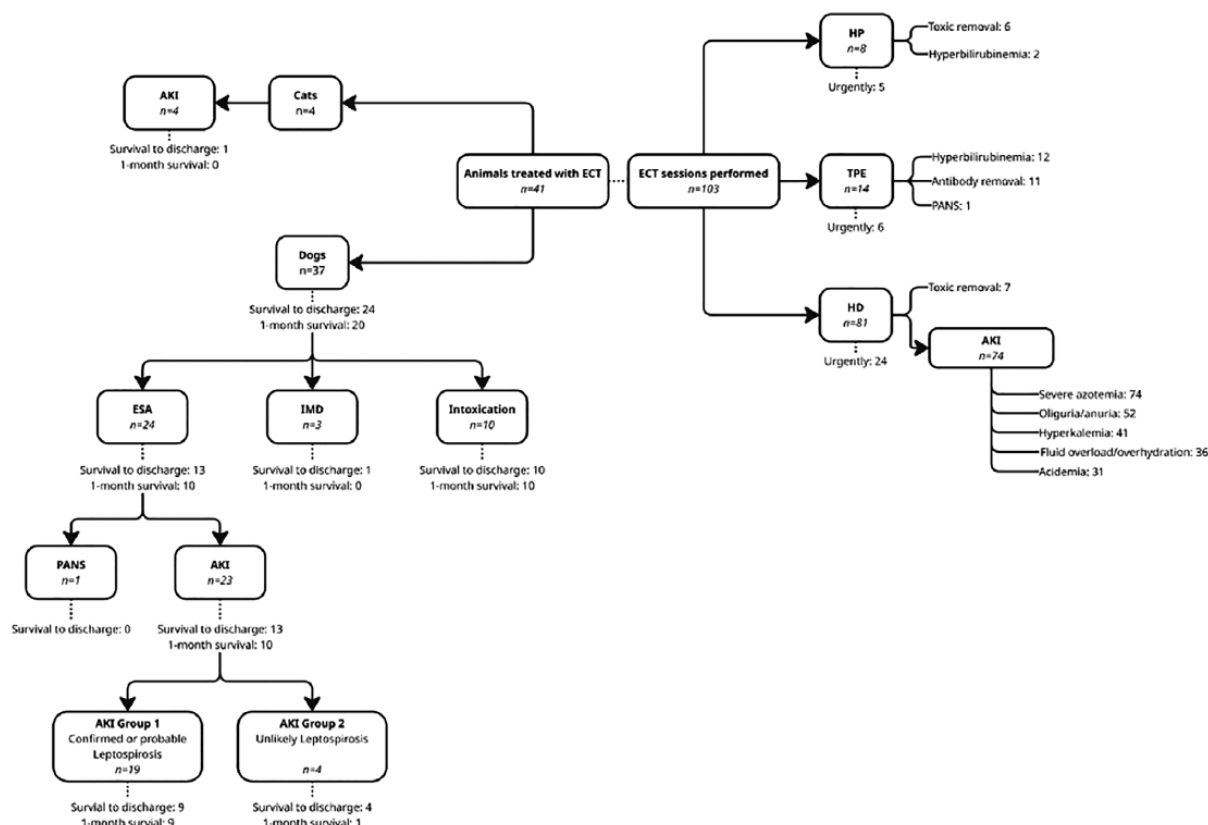


Figure 1 | Therapy modality overlaps among 41 animals treated with extracorporeal therapies. AKI group 1 includes dogs with probable or confirmed leptospirosis, and AKI group 2 includes dogs with unlikely leptospirosis and cats. AKI, acute kidney injury; HD, hemodialysis; HP, hemoperfusion; IMD, immune-mediated disease; PANS, post-attenuation neurologic signs; TPE, therapeutic plasma exchange.

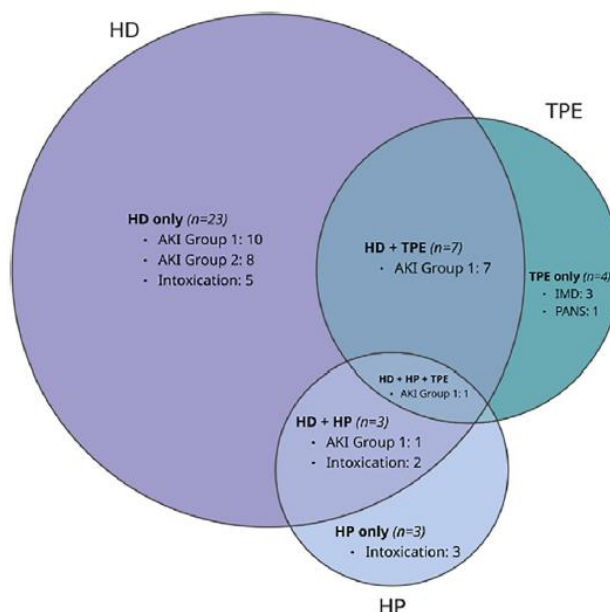


Figure 2 | Integrated flowchart of animal indications and outcomes alongside extracorporeal therapy sessions and therapeutic targets. AKI, acute kidney injury; ESA, endogenous substance accumulation; HD, hemodialysis; HP, hemoperfusion; IMD, immune-mediated disease; PANS, post-attenuation neurologic signs; TPE, therapeutic plasma exchange.

Table 2 | Diagnosis and associated ECT modality applied.

Group	Subgroup	Diagnosis	N	Species	ECT modality applied
ESA	Acute kidney disease	Leptospirosis (confirmed probable)	19	Dog	HD (19), TPE (8), HP (2)
		Unknown etiology	5	Dog (3) Cat (2)	HD (5)
		Glomerulonephritis	1	Dog	HD (1)
		Ureteral obstruction	2	Cat	HD (2)
	Post-attenuation neurologic signs		1	Dog	TPE (1)
IMD		IMHA	2	Dog	TPE (2)
		Polymyositis	1	Dog	TPE (1)
Intoxication		Aniline	3	Dog	HD (1), HD + HP (1), HP (1)
		Chocolate	2	Dog	HD (2)
		NSAID	1	Dog	HP (1)
		Phenobarbital	1	Dog	HP (1)
		Paracetamol (acetaminophen)	1	Dog	HD (1)
		Mycotoxin (suspected)	1	Dog	HD + HP (1)
		Ethylene glycol	1	Dog	HD (1)

Abbreviations: ECT, extracorporeal therapy ; ESA, endogenous substance accumulation; HD, hemodialysis; HP, hemoperfusion; IMD, immune-mediated disease; IMHA, immune-mediated hemolytic anemia; NSAID, nonsteroidal anti-inflammatory drug; TPE, therapeutic plasma exchange.

3.3 OUTCOMES

Among the animals with ESA, 13 of 23 dogs with AKI survived to discharge, 10 of which were still alive 1 month later. Most nonsurvivors in AKI group 1 (confirmed or probable leptospirosis [10/19]) were euthanized due to poor prognosis associated with severe pulmonary bleeding (2/10) or other

complications, such as intussusception (1/6), bronchopneumonia (1/10), or hemodynamic instability secondary to sepsis (2/6). Other nonsurvivors died naturally from severe pulmonary bleeding (3/10) or sepsis (1/10). All dogs in AKI group 2 (4/4) survived to discharge. The dog treated for PANS in the ESA group was euthanized a few hours after TPE due to the need for mechanical ventilation and financial constraints.

All cats with AKI treated with HD died naturally during hospitalization from complications related to their primary disease (3/4) or before 1 month after discharge (1/4). AKI group 1 dogs (confirmed or probable leptospirosis) had a superior 1-month outcome (9/19 [47%]) compared with AKI group 2 (1/4 [25%]) ($p = 0.014$).

Within the IMD group, one dog with IMHA survived to discharge but was euthanized a few days later for severe gastrointestinal bleeding. The other dog affected by IMHA was euthanized due to acute neurologic signs. The dog suffering from polymyositis experienced cardiac arrest during mechanical ventilation. All dogs treated for intoxication (10/10) survived to discharge and remained alive 1 month later. Treatment indication was associated with survival to discharge ($p = 0.006$), with dogs treated for intoxication (10/10) showing a higher discharge survival rate compared with those in the AKI group (13/23) or the IMD group (1/3). Age, sex, and body weight were not associated with discharge rate.

3.4 ECT PERFORMED, URGENCY OF TREATMENT, AND THERAPEUTIC TARGETS

A total of 103 ECT sessions were performed, with 81 being HD treatments, 14 TPE, and eight HP. The distribution of therapies among patients is summarized in **Figure 2**. The most common indication for HD was AKI (74/81 treatments). Among the 74 treatments performed in patients with AKI, severe or progressive azotemia was consistently present (74/74), with additional abnormalities including oliguria/anuria (52/74), hyperkalemia (41/74), fluid overload/overhydration (36/74), and acidemia (31/74). Suspected intoxications (7/81 treatments) comprised the other indications for HD. Twenty-four of 81 HD sessions were considered urgent treatment. The median number of treatments per patient was 2 (range: 1–15). Sixty of 81 HD treatments were performed on the continuous platform, whereas the intermittent platform connected to a water purification device was used for 21 HD sessions. Although body weight did not differ between animals treated with a continuous versus an intermittent device ($p = 0.072$), all animals weighing < 10 kg were managed with the continuous device. Similarly, device selection did not differ according to the degree of urgency ($p = 0.074$) or between AKI and intoxication cases ($p = 0.867$).

Among the 14 TPE sessions, therapeutic targets were severe hyperbilirubinemia in 12 of 14 sessions, antibody removal in 11, and PANS in one. Six of 14 sessions were performed urgently, five of which were performed with HD in series in dogs with confirmed or probable leptospirosis-induced pulmonary hemorrhage.

Eight HP sessions were performed for suspected intoxication (4/8), ingestion of toxic substances or drug overdose (2/8), and hyperbilirubinemia (2/8), five of which were performed as urgent treatment.

Anticoagulation was achieved with systemic heparinization in 86 of 103 sessions, low heparinization in 11, regional citrate anticoagulation in one, and no anticoagulation in five. Low heparinization was used exclusively in animals considered at risk of bleeding due to severe thrombocytopenia or increased

pretreatment aPTT. Evidence of bleeding at treatment initiation was seen in all animals receiving regional citrate anticoagulation and those receiving no anticoagulation.

3.5 ECT-ASSOCIATED COMPLICATIONS

Vascular access complications occurred in nine of 41 animals, all of which were dogs. Complications related to catheter placement were infrequent and included the need for a second insertion site (3/41) or the requirement for a cut-down procedure (2/41). One case experienced clinically meaningful bleeding at the insertion site during catheter placement. Simple manual compression did not resolve the hemorrhage, and surgical intervention (surgical cut-down and electrocoagulation) and a transfusion of packed RBCs and fresh frozen plasma were required. This hemorrhage was suspected to be related to severe coagulopathy, documented with markedly increased aPTT (> 300 s, reference interval: 72–102) and a severe thrombocytopenia ($26,000/\mu\text{L}$; reference interval: 148–484,000). Vascular access complications between or during sessions included catheter obstruction due to catheter clotting (3/41) and catheter leak resulting from a perforation in the external segment of one of the catheter lumens (2/41).

The treatment complication rate during sessions was 27% for HD (22/81), which was lower ($p = 0.012$) than for HP (72% [5/8]) and TPE (64% [9/14]). The most common complications during ECT included circuit clotting (10/81), bleeding (9/81), and hypotension/hypovolemia (4/81) for HD; circuit clotting (5/8) for HP; and hypocalcemia (9/14) and hypotension (5/14) for TPE. The occurrence of complications was not associated with either the animal's body weight ($p = 0.848$) or the urgency status of the ECT session ($p = 0.800$).

Among the nine cases in which bleeding events were observed during sessions, one had been performed without anticoagulation, one under regional citrate anticoagulation, and the others with systemic heparinization. Of these, one had aPTT above the therapeutic target (> 200 s). For the 10 cases in which circuit clotting was observed, three were performed under low-heparin protocols and the others with normal systemic heparinization. Six of 10 cases had aPTT values below the therapeutic target (< 150 s).

4. Discussion

This retrospective study describes the indications, techniques, complications, and outcomes of ECT in 37 dogs and four cats treated at a veterinary teaching hospital during the first year after the ECT program was implemented. The results obtained after this first year seem to align with previous reports, highlighting a moderate to high complication rate, mostly transient with mild severity.

Only four cats received ECT. This low representation is largely explained by the technical challenges and costs associated with extracorporeal procedures in feline patients. The small size of most cats requires miniaturized circuits and tighter hemodynamic control and often mandates blood product transfusions to prevent dilutional anemia and reduce hemodynamic instability during the treatment, which increases both the complexity and cost of treatment [1, 27].

Most ECT sessions in the current retrospective study were HD procedures, primarily performed for AKI to manage progressive or severe azotemia, hyperkalemia, volume overload, and acid–base imbalances. These findings align with previous veterinary literature describing animals undergoing HD for management of AKI, in which hyperkalemia is reported in 30% of dogs and 50% of cats, volume overload in 60%–75% of dogs, and anuria in 32% of dogs and 53% of cats [28–30]. In contrast, the use of TPE was less frequent and mainly targeted antibody removal in IMD, notably in cases of IMHA, as previously described [7, 9, 31], or in addition to HD in cases of leptospirosis-induced pulmonary hemorrhage. TPE for targeted antibody removal has been suggested in human literature, as pulmonary hemorrhage in leptospirosis seems to be at least partially due to an immune-mediated process [32, 33]. In our cohort of dogs with leptospirosis treated with TPE in addition to HD for pulmonary hemorrhage, five of 10 survived to discharge despite severe bleeding and the need for intensive support, such as high-flow nasal oxygen therapy or mechanical ventilation. Nevertheless, given the study design, no conclusion can be drawn regarding the potential benefit of TPE as an adjunct therapy for leptospirosis-induced pulmonary hemorrhage.

In our case series, one dog was treated with TPE for PANS. In veterinary medicine, the use of TPE for hepatic encephalopathy has only been reported once, in a dog with refractory hyperammonemia secondary to a portosystemic shunt, in which clinical improvement coincided with a decrease in plasma ammonia [34]. The application of TPE in PANS remains speculative given the absence of a conventionally measurable solute. However, a feline case report suggested a potential beneficial effect, describing rapid resolution of post-attenuation seizures after TPE [35]. In our retrospective study, the dog treated with TPE for PANS was euthanized a few hours after treatment due to the need for mechanical ventilation and financial constraints, which did not allow evaluation of the potential benefit of therapy. HP was used for both intoxication and severe hyperbilirubinemia. Reduction of hyperbilirubinemia through HP has been previously reported in people [36] but not in veterinary patients, in which TPE has been used in previous reports [37, 38].

Most animals in this case series received systemic heparinization during treatments. Those considered at increased risk of bleeding but without evidence of hemorrhage were given a reduced heparin dose, whereas animals with documented hemorrhage were managed without anticoagulation, despite current guidelines recommending the use of regional citrate anticoagulation [1]. This deviation was due to the unavailability of citrate at our institution during most of the study period. Only one dog with leptospirosis-associated pulmonary hemorrhage underwent regional citrate anticoagulation. This dog experienced major pulmonary bleeding during the session. Regional citrate anticoagulation provides anticoagulation in the extracorporeal circuit but does not interfere with the patient's hemostasis [26]. Because the dog had calcium concentrations within reference guidelines (0.8–1.2 mmol/L) [26] throughout the procedure, the bleeding was considered unlikely to be related to the citrate anticoagulation protocol.

Treatment complication rates were moderate to high, with 27% for HD, 72% for HP, and 64% for TPE. These findings are consistent with previous reports in veterinary literature, where complication rates between 18% and 79% have been observed depending on the technique used [1, 7, 9, 18–21]. Most complications were mild and included circuit clotting, bleeding, transient hypotension, and electrolyte disturbances, such as hypocalcemia in TPE. Previous veterinary studies described coagulation-related complications in 10%–20% of cases [7, 9], ultrafiltration-related complications in 26% (including hypotension [39]), and hypocalcemia due to citrate overload in TPE in 79% [7]. Complication rates of TPE

reported in people range from 10% to 30% [40–43]. The differences in complication rates may be explained by patient characteristics, with veterinary patients more often presenting with more acute conditions. Complications reported in the current study were unlikely to be associated with mortality, which supports previous findings that ECT, while invasive, can be performed safely in companion animals in a controlled hospital setting [1].

Many treatments (34%) were performed urgently, often out of hours. The main indications for performing ECT urgently were intoxicated patients, patients with AKI with refractory severe hyperkalemia or fluid overload, or dogs with leptospirosis-induced pulmonary hemorrhage. No increase in complications was observed in the urgent cases compared with nonurgent ones, an observation consistent with human ECT, such as extracorporeal membrane oxygenation, in which urgent initiation is not associated with higher complication rates [44, 45]. This potential risk may be mitigated by the presence of smaller, more cohesive teams and rapid decision-making. This finding is in contrast to surgical emergencies, in which timing and team fatigue can meaningfully influence patient outcomes [46–48].

Outcomes in our population varied according to the indication for ECT. All animals treated for intoxication survived and were in good health 1 month after discharge, while survival was lower in dogs treated for AKI (57%) or IMD (33%). These results align with earlier veterinary studies showing favorable outcomes for patients treated with ECT in the context of acute exposures, particularly when the toxic substance has well-defined pharmacokinetic properties and limited organ damage has occurred at the time of presentation [9–16]. In the subgroup of patients with AKI managed with ECT, the survival rate is consistent with previous studies that reported survival rates between 44% and 66% [19, 49, 50]. Dogs with confirmed or probable leptospirosis had a significantly higher 1-month survival rate compared with dogs with AKI and unlikely leptospirosis. This finding echoes published data suggesting that the renal injury observed in leptospirosis is often reversible with intensive care, unlike other etiologies that may involve more severe or permanent damage [2, 29, 30, 49, 51, 52]. Leptospirosis status was classified as confirmed or probable or unlikely based on a combination of diagnostic results and clinical assessment, as previously recommended by Sykes et al. [24]. Nevertheless, this approach may introduce a degree of subjectivity and can be considered a limitation that should be acknowledged when interpreting the results of the subgroup analyses.

Although cats appeared to have a poorer outcome compared with dogs, this should be interpreted with extreme caution due to the very limited number of cats included in the study. This finding does not align with the results reported in other studies. Indeed, Eatroff et al. reported similar survival rates between cats and dogs undergoing intermittent HD for AKI (38% vs. 33% 1 year after discharge) [50]. Langston et al. found no significant association between species and survival outcomes in dialyzed patients [27], and Legatti et al. concluded that although pooled mortality appeared slightly higher in cats (53%) than in dogs (45%), this difference was not statistically significant [49]. The apparently poorer outcome in cats observed in our cohort might reflect factors other than species itself, such as severity of underlying disease process (often suspected acute-on-chronic kidney disease), smaller body weight and blood volume, which may limit tolerance to extracorporeal circulation, or the occurrence of concurrent complications. However, given the small sample size, these considerations remain speculative, and larger studies would be required to better investigate potential species-related differences in prognosis.

Only three dogs with IMD were managed with TPE during the studied period, and all died during hospitalization or before 1 month after discharge. The low number of patients undergoing TPE prevents conclusions from being drawn from these data. Previous papers on TPE in dogs treated for hematologic IMD reported a survival-to-discharge rate between 75% and 86% [5, 7, 34].

Case selection is also likely to have influenced success and complication rates in our cohort. Intoxication cases were often included when no irreversible damage had yet occurred (e.g., early ethylene glycol ingestion), which may explain the more favorable outcomes. In contrast, dogs with AKI were often referred only after failing to respond to conventional therapy, which may negatively impact prognosis. Similarly, IMD was generally treated with ECT only in refractory cases. Earlier intervention might improve success rates, in particular when dialytic intervention is applied in patients with AKI before multiorgan failure [1], although further studies are needed to determine the true impact of case selection on outcome and complications.

This study regarding current veterinary ECT practices has several important limitations. First, the retrospective design inherently limits control over data quality and introduces potential biases, including during selection and reporting. Second, the small sample size and heterogeneity of cases (regarding indication, ECT modality, disease severity, and comorbidities) reduce the statistical power of the study and preclude robust subgroup analysis or risk factor modeling. The absence of a control group not receiving ECT limits the ability to attribute observed outcomes directly to the ECT intervention rather than to concurrent treatments or natural disease course.

The single-center nature of the study also restricts the external validity of the findings, as patient demographics, technical protocols, and clinician experience may differ across institutions. This brings into focus an important but underreported factor in veterinary ECT: the operator and institutional learning curve. The technical complexity of ECT, ranging from vascular access placement to case selection and anticoagulation management, implies that clinician experience could significantly influence both patient outcomes and the incidence of complications, such as circuit clotting, hypotension, or hypocalcemia [53, 54]. Monitoring the evolution of complication rates and survival outcomes over time within a single institution could help quantify this learning curve and identify modifiable factors that contribute to procedural success.

In conclusion, ECT appears to be a feasible and relatively safe option for the management of select dogs and cats that are critically ill, even in the early stages of program implementation, facilitated by the emergence of veterinary consensus guidelines or training programs delivered by experts in the field. Although complication rates remain moderate to high, they are mostly mild. The indication for treatment may affect the outcome, with a favorable prognosis seen in dogs treated for intoxications or patients with AKI associated with leptospirosis.

Author Contributions

Etienne Escande : investigation, conceptualization, writing – original draft, methodology, formal analysis, data curation, visualization, project administration, software. **Nicolas Graziano** : investigation,

writing – review and editing, conceptualization. **Kris Gommeren** : writing – review and editing, supervision, resources, project administration, conceptualization, methodology, validation.

Conflicts of Interest

The authors declare no conflicts of interest.

Endnotes

- ¹Multifiltrate, Fresenius Medical Care, Bad Homburg, Germany.
- ²5008s Cordiax, Fresenius Medical Care.
- ³AquaUno, Fresenius Medical Care.
- ⁴HP Vive, AimaLojic, Rapid City, SD.
- ⁵Vet DU 100ml, AimaLojic.
- ⁶P1dry, Fresenius Medical Care.
- ⁷Voluven, Fresenius Kabi, Louviers, France.
- ⁸Alburex 20, CSL Behring GmbH, Marburg, Germany.
- ⁹CoagDx, IDEXX Laboratories, Westbrook, ME.
- ¹⁰XLSTAT software version 2025.1.1.1429, Lumivero, Denver, CO.

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