



CASE REPORT OPEN ACCESS

Modified Manual Therapeutic Plasma Exchange Technique as a Successful Treatment for Postattenuation Neurological Signs (PANS) in a Dog

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ABSTRACT

Objective: To investigate and describe the therapeutic potential of manual plasma exchange for controlling seizures and neurologic dysfunction in a dog with postattenuation neurologic signs (PANS).

Case Summary: A 4-year-old neutered female Yorkshire Terrier was initially diagnosed using computed tomography with a congenital extrahepatic portosystemic shunt involving the left gastric and azygos veins. After diagnosis, surgical correction of the anomaly was performed without complications, and the patient was discharged. However, within 48 h of surgery, the dog developed a neurologic condition characterized by generalized tonic-clonic seizures that were poorly responsive to medical treatment. Given the timing and progression of clinical signs despite medical therapy, and after ruling out hepatic encephalopathy as a likely cause, a presumptive diagnosis of PANS was established. A modified, manual therapeutic plasma exchange (MTPE) technique was successfully performed over an 8-h period with minimal complications. After the procedure, marked clinical improvement was observed, with resolution of neurologic signs, and the patient was discharged without further procedure-related complications.

New or Unique Information Provided: PANS has been described in veterinary medicine in both dogs and cats, although its etiology and treatment remain poorly understood. This report describes the use of MTPE as a therapeutic approach, yielding promising results. To the authors' knowledge, this is the first documented use of MTPE for this condition in dogs, with previous reports limited to a single case in a cat.

1 | Introduction

Congenital portosystemic shunt (CPSS) is a vascular malformation that redirects portal circulation into the systemic circulation, bypassing the hepatic circulation [1]. Extrahepatic portosystemic shunts are more common in small breeds, such

as Yorkshire Terriers and Miniature Poodles, whereas intrahepatic portosystemic shunts are more frequently observed in large breeds, including Labrador Retrievers and Irish Setters [2, 3]. Notably, this condition is less common in cats, with domestic shorthair cats being the most frequently affected breed [4].

Abbreviations: aPTT, activated partial thromboplastin time; BV, blood volume; CPSS, congenital portosystemic shunt; CRI, continuous rate infusion; MRI, magnetic resonance imaging; MTPE, manual therapeutic plasma exchange; PANS, postattenuation neurologic signs; RI, reference interval; TPE, therapeutic plasma exchange.

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The treatment of choice for CPSS is surgical correction, but it is not without complications, including portal hypertension, hypoglycemia, and postattenuation neurologic signs (PANS) [5, 6]. The latter, also referred to as postoperative neurologic signs, has been reported in 14.3%–62.0% of cats and 2.6%–27.3% of dogs, making it a common postoperative complication [7–11]. Initially, these signs were termed postattenuation seizures after a postattenuation seizure syndrome was observed in a group of three dogs that had not previously exhibited seizures [12]. Currently, the term PANS encompasses all neurologic signs occurring within 7 days postoperatively, including seizures, depression, muscle twitching, behavioral changes, ataxia, and tremors [13, 14]. Notably, signs do not appear to be associated with hyperammonemia, electrolyte imbalances, or hypoglycemia, and often remain refractory even after complete shunt ligation [5, 10, 15]. Despite its unclear etiology, PANS is speculated to be linked to central nervous system metabolic disturbances, concurrent congenital or acquired brain disorders, portal hypertension, or infectious disease, although no definitive causal relationship has been established [10, 11]. Additionally, factors such as breed, advanced age, hepatic encephalopathy, and shunt type have been suggested as potential risk factors [10].

The treatment of PANS is challenging, partly due to its unknown etiology. Consequently, the therapeutic approach focuses on supportive care and the management of neurologic symptoms [10]. Various drugs, including benzodiazepines, levetiracetam, barbiturates, and propofol, have been proposed for symptom control; however, their efficacy remains unclear, and results have been variable [13, 15–18]. Therapeutic plasma exchange (TPE), an extracorporeal blood purification technique, has been successfully used to treat PANS in one cat [19]. However, despite its well-documented applications in veterinary medicine for autoimmune, metabolic, and toxic disorders, the potential of TPE for treating PANS in dogs remains unexplored [20–22]. To the best of the authors' knowledge, this report describes the first successful use of manual therapeutic plasma exchange (MTPE) to effectively treat PANS and halt the progression of neurologic signs in a dog.

2 | Case Report

A 4-year-old neutered female Yorkshire Terrier weighing 3 kg was referred to Fundació Hospital Clinic Veterinari UAB for further evaluation due to dullness, lethargy, ataxia, and small stature. Upon referral, the dog had been receiving medical management for 3 months for a suspected CPSS. Included in the diagnostic workup was a computed tomography scan, which confirmed a congenital extrahepatic portosystemic shunt involving the left gastric vein and azygos vein. No other abnormalities were detected on imaging or laboratory tests, and the dog subsequently underwent surgical correction with the placement of a cellophane band¹ around the shunt. The patient was discharged 1 day after surgery without complications. However, 48 h after surgery, the dog returned to the emergency service with a neurologic condition characterized by seizures with autonomic signs.

On admission, the patient exhibited obtundation, slightly pale mucous membranes, and a temperature of 40.9°C. Neurologic examination revealed nonambulatory tetraparesis, pleurotho-

tonus, absence of bilateral menace response, and positional, disconjugate nystagmus. Blood work performed on admission included a CBC², serum biochemical profile³, plasma ammonia concentration measurement³, coagulation panel⁴, and acid–base analysis⁵. Detected abnormalities included moderate nonregenerative, microcytic, hypochromic anemia (Hct 28%; reference interval [RI]: 37%–55%), lymphopenia (0.90 K/ μ L; RI: 1.05–5.10 K/ μ L), and thrombocytopenia (125 K/ μ L; RI: 148–484 K/ μ L); serum BUN concentration 6 mg/dL (RI: 7–27 mg/dL [2.1 mmol/L, RI: 2.5–9.6 mmol/L]), chloride concentration 107 mmol/L (RI: 109–122 mmol/L), albumin concentration 20 g/L (RI: 23–40 g/L [2 g/dL, RI: 2.3–4 g/dL]), and cholesterol concentration 1.81 mmol/L (RI: 2.84–8.28 mmol/L [70 mg/dL, RI: 110–320 mg/dL]); and plasma ammonia concentration 60 μ mol/L (RI: 0–98 μ mol/L). Additionally, an increased activated partial thromboplastin time (aPTT) of 121 s (RI: 72–102 s) was observed, while the remaining analytical parameters were within normal limits. Imaging studies did not reveal significant abnormalities, ruling out portal hypertension and confirming visible blood flow through the shunt. Advanced diagnostic imaging techniques, such as magnetic resonance imaging (MRI) and cerebrospinal fluid analysis, were declined by the owner.

The patient was hospitalized in the ICU with supportive care and continuous monitoring for suspected PANS following portosystemic shunt surgery. Antiseizure medication was initiated, including levetiracetam⁶ (a loading bolus of 60 mg/kg, IV, followed by a dose of 20 mg/kg, IV, q 8 h) and midazolam⁷ (0.3 mg/kg, IV, as needed for seizures). Despite this treatment, the dog continued to experience cluster seizures, necessitating further escalation of medication; therefore, a propofol⁸ continuous rate infusion (CRI) (0.1–0.4 mg/kg/min) was started. At this time, mechanical ventilation was considered necessary; however, the owners declined endotracheal intubation. Consequently, supplemental oxygen and intensive monitoring (ECG, pulse oximetry, nasal carbon dioxide, blood pressure, and urinary output) were performed, and daily arterial blood gas analysis was performed to guide respiratory management. The patient was positioned head-up to reduce aspiration risk, and prokinetics including metoclopramide⁹ (2 mg/kg/day, CRI) and erythromycin¹⁰ (1 mg/kg, IV, q 8 h) were administered to enhance gastric motility. Maropitant¹¹ (1 mg/kg, IV, q 24 h) was also given as an antiemetic. Seizure activity did not improve over the next 24 h, and dexmedetomidine¹² (3–7 μ g/kg/h) was added, along with ketamine¹³ (1 mg/kg/h). The initial response to these last two medications was positive, with a marked reduction in both frequency and severity of the episodes; however, attempts to de-escalate the dosages over the next 48 h was unsuccessful. During this time, the dog remained hemodynamically stable.

Given the persistence of signs and refractoriness to medical treatment, and after considering the limited therapeutic options, TPE was proposed to the owners as a rescue therapy for the PANS-related disorder. Because our institution lacked access to a centrifuge for complete separation of RBCs and plasma, a modified technique in which RBCs and plasma were substituted at the same time was discussed with the owners.

The patient was connected to a multiparameter monitor¹⁴, where ECG, noninvasive blood pressure, and pulse oximetry were continuously monitored. CBC, serum biochemical profile,

TABLE 1 | Analytical parameters monitored during the modified manual plasma exchange in a 4-year-old neutered female Yorkshire Terrier with suspected postattenuation neurologic signs following attenuation of a congenital extrahepatic portosystemic shunt.

	Baseline	After the second cycle	After the fourth cycle	After the sixth cycle	Two hours after completing the procedure
pH (7.32–7.42)	7.43	7.44	7.53	7.53	7.54
PCV (37%–55%)	31	30	30	30	31
Na (144–160 mmol/L)	143	141.9	141.9	141	142.7
K (3.5–5.8 mmol/L)	4.07	3.25	3.25	2.96	4.71
Cl (109–122 mmol/L)	114.8	115.3	115.3	111.1	113.3
iCa (1.25–1.5 mmol/L)	1.23	1.12	1.12	1.23	1.19
iMg (0.43–0.7 mmol/L)	0.56	0.35	0.35	0.4	0.43
Glucose (3.9–7.9 mmol/L) [70–143 mg/dL]	6.4 [116]	4.3 [77]	4.3 [77]	4.5 [81]	5.4 [97]
Lactate (0.5–2.5 mmol/L)	0.9	0.8	0.8	0.7	0.8
Creatinine (44.2–159.2 mmol/L) [0.5–1.8 mg/dL]	53.1 [0.6]	61.9 [0.7]	61.9 [0.7]	61.9 [0.7]	70.7 [0.8]

coagulation, and blood gas analysis were performed, with no significant changes observed compared with prior results. The dog was blood-typed, and before the procedure, both major and minor crossmatches¹⁵ were performed with multiple blood units to minimize the potential of transfusion reaction. A 7-Fr × 13-cm double-lumen central catheter¹⁶ was placed in the left jugular vein using the modified Seldinger technique.

The patient's blood volume (BV) was estimated to be 90 mL of blood per kilogram of body weight (90 mL × weight in kg), and the total plasma volume was calculated using the following formula: $BV \times (1 - \text{hematocrit})$. The estimated plasma volume to be exchanged was 1.5 times the patient's plasma volume, which equated to a total of 291 mL. With a hematocrit of 28%, the plasma volume was estimated to be approximately 72%. Considering the small size of the patient and the high volume of plasma to be exchanged, we estimated that six cycles of 50 mL of blood each would be required to achieve the desired plasma volume exchange.

Using a sterile technique, 60-mL syringes were prefilled with 1 mL of citrate-phosphate-dextrose-adenine-1 for every 7 mL of whole blood. While continuously monitoring the patient, a steady technique was used to collect 50 mL of whole blood per cycle. Each extraction lasted between 5 and 10 min. After each extraction, the patient was transfused over 10–15 min using an in-line hemofilter with a mixture of packed RBCs and fresh frozen plasma in a 45% to 55% ratio, respectively. Recovery periods between cycles averaged 30 min. In total, the entire process required approximately 8 h to complete. Interestingly, the patient's mental status steadily improved after each cycle. Venous blood gas analysis⁵ was performed every two cycles (Table 1). Apart from a single episode of moderate hypokalemia, which responded to supplementation, no other major complications were detected. Reassessment of coagulation parameters, prothrombin time and aPTT, revealed no abnormalities at the end of the procedure. However, the postprocedure hemogram revealed thrombocytopenia of 94 K/ μ L (RI: 148–484).

Due to the positive response to treatment, the CRIs of ketamine and dexmedetomidine were discontinued after the final cycle. A neurologic examination at that time revealed mild generalized tremors, bilateral vision loss, positional nystagmus, and non-ambulatory tetraparesis. The CRIs of propofol and midazolam were gradually tapered over the following hours and completely discontinued within 24 h after the procedure, with no further episodes of seizure activity. Levetiracetam was continued every 8 h at a dose of 20 mg/kg, along with supportive care. The patient showed progressive improvement over the first 48 h and began eating and drinking voluntarily. Neurologic improvement was observed over the next 5 days, and the dog achieved an alert mental status and voluntary movement, although bilateral menace response remained absent. The dog was discharged with levetiracetam (20 mg/kg, q 8 h), metronidazole (7.5 mg/kg, PO, q 24 h), lactulose (0.5 mL, PO, q 12 h), and a low-protein diet, which was progressively weaned during the next 3 months given the continuous improvement observed. Two weeks after discharge, the patient was rechecked and had fully regained visual capacity and was ambulatory without assistance. The final follow-up was conducted 3 months after discharge, with the owners reporting no abnormal neurologic activity.

3 | Discussion

PANS is a potential complication described in dogs and cats associated with the postoperative period following CPSS attenuation and includes various neurologic abnormalities, such as seizures, blindness, or ataxia [13]. Its complex and unknown etiology complicates treatment, which focuses on supportive measures and the use of antiepileptic drugs [11, 12]. When standard medical management is ineffective and the clinical condition progresses with persistent and drug-resistant seizures, TPE may be considered, as has been described in a cat with PANS [19] and in other neurologic conditions such as myasthenia gravis or polyradiculoneuritis in veterinary medicine [23]. However, despite the promising results of individual cases, the absence of molecules specifically linked

to PANS prevents a recommendation of TPE for this indication based on solid scientific evidence.

The dog in our report was presumptively diagnosed with PANS based on history of recent CPSS attenuation, the sudden onset of neurologic symptoms after surgery, the absence of these signs preceding surgical attenuation, and the lack of laboratory abnormalities, such as hyperammonemia to otherwise explain the condition. Advanced imaging studies like MRI, which could have supported the diagnosis, were not possible due to financial constraints, leading to the use of MTPE as a last resort to avoid euthanasia.

Culler et al. [22] described the use of MTPE in a dog presenting with neurologic signs also associated with hepatic vascular anomalies; a similarly favorable outcome was seen after the procedure. However, the dog in their case deteriorated after anesthesia was administered for a computed tomography scan, performed to confirm a diagnosis of hepatic encephalopathy. While that case report represented the first published use of this technique in a dog with neurologic signs of metabolic origin, it does not represent a case of PANS, as it occurred before surgical attenuation of the vascular anomaly. In addition, the therapeutic approach differed. In the Culler et al. case, the plasma was purified and returned to the patient, whereas in our case, both plasma and red blood cells were replaced.

It is important to note that the therapeutic relevance of plasma exchange primarily lies in its ability to remove harmful substances from the intravascular compartment [21]. Therefore, the success of this technique depends, among other factors, on the kinetics of the harmful molecules involved in relation to the blood and extravascular compartments. As a result, multiple cycles may be necessary before achieving significant clinical outcomes, and accurate calculations of the plasma volume to be exchanged are crucial. This is particularly challenging in conditions like PANS, given the uncertain nature of the molecules involved. In human medicine, literature suggests that to remove approximately 75% of the substances present in the plasma, it is necessary to exchange 1.5 times the patient's plasma volume [24]. In veterinary medicine, although references are more scarce, some authors mention exchanges of 1.2, 1.7, or even 2 times the animal's plasma volume achieving up to 80% removal of certain solutes from plasma [19, 21]. In the current report, given the patient's characteristics, the calculated exchange was 1.5 times the plasma volume.

The use of extracorporeal therapies, especially when using the automated modality, can be complex in small-sized patients such as cats or dogs weighing less than 10 kg [19]. This is due to the ratio between the patient's BV and the device's volume, which can lead to significant reductions in hematocrit during the procedure. However, with an accurate prescription, the automated modality was a feasible option in our institution. Due to the high cost for owners, we ultimately opted to offer MTPE, as it provided a significant cost reduction and was deemed appropriate based on the patient's weight.

Among the limitations of this therapy, the various complications that can arise with any blood transfusion or blood product administration should be considered [25]. Contamination is a

primary concern, particularly considering the repetitive manual process, in which repeated handling of an open circuit increases the risk. This highlights the importance of maintaining strict asepsis throughout the procedure.

In this case report, a complete blood exchange, including both plasma and cellular components, was performed due to the unavailability of an appropriate centrifuge for manual blood separation. Additionally, whole blood transfusion was not possible because at the time of the procedure, no prescreened donor was available for the safe collection of whole blood. Consequently, canine plasma and packed RBCs obtained from a local blood bank were used, having undergone compatibility testing¹⁴ before transfusion to minimize the risk of posttransfusion reactions. This modification of the commonly used protocol, which typically involves exchanging only plasma, was a challenge due to the lack of literature regarding the volume of packed RBCs that should be transfused. Therefore, we estimated that on every extraction, the PCV would decrease by 8%; with our transfusion, we would replace 7.5%, allowing us to maintain the patient's original PCV. Indeed, at the end of the procedure, the patient's PCV was 31%, slightly higher than prior to MTPE.

Several analytical abnormalities were detected after the procedure, including transient thrombocytopenia, mild ionized hypocalcemia, mild ionized hypomagnesemia, and moderate hypokalemia. Thrombocytopenia was associated with platelet removal during the procedure with no targeted replacement during blood transfusion. We did not identify any bleeding complication that could be associated with the thrombocytopenia, and it resolved over the next 48 h without further intervention. The electrolyte abnormalities detected were associated with massive transfusion. Only hypokalemia required supplementation and resolved without complication.

The patient described in this case report showed a rapid clinical response to treatment. Although additional diagnostic procedures, such as MRI and CSF analysis, could not be performed due to financial constraints, the patient improved without further intervention after MTPE. These findings suggest that this technique could be beneficial and should be considered in other dogs with a presumptive diagnosis of PANS.

This case report hypothesized the therapeutic potential of a modified MTPE technique for the treatment of PANS in dogs. In our case, the patient showed favorable progress after this technique was used in conjunction with appropriate supportive therapy, allowing for discharge and maintaining a good quality of life for several months. To the authors' knowledge, this is the first description of this technique for the treatment of PANS in dogs. Given that the etiology of this disease remains unknown, studies are needed.

Author Contributions

Marcos Fumero-Hernández: conceptualization, investigation, writing – original draft, methodology. **Marta Ribas:** conceptualization, investigation, methodology. **Patricia Bou:** conceptualization, investigation, methodology. **Carlos Torrente:** conceptualization, investigation, methodology, supervision. **Luis Bosch:** conceptualization, investigation,

writing – original draft, methodology, writing – review and editing, supervision.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Research data are not shared.

Endnotes

- ¹ CelloVet, CelloVet Pty Ltd, Fremantle, Australia.
- ² IDEXX ProCyt Dx, IDEXX Laboratories Iberia, Sant Cugat del Vallès, Barcelona, Spain.
- ³ IDEXX Catalyst One, IDEXX Laboratories Iberia.
- ⁴ IDEXX Coagulation Analyzer, IDEXX Laboratories Iberia.
- ⁵ Stat Profile Prime Plus, Nova Biomedical Iberia, Sant Cugat del Vallès, Barcelona, Spain.
- ⁶ Keppra, UCB Pharma, Madrid, Spain.
- ⁷ Midazolam Normon, Laboratorios Normon, Madrid, Spain.
- ⁸ Propofol Lipuro, B. Braun, Rubí, Barcelona, Spain.
- ⁹ Metoclopramida EFG, Kern Pharma, Terrassa, Barcelona, Spain.
- ¹⁰ Pantomicina, Ferrer Internacional, S.A., Barcelona, Spain.
- ¹¹ Cerenia, Zoetis, Barcelona, Spain.
- ¹² Dexdomitor, Zoetis, Madrid, Spain.
- ¹³ Ketaset, Zoetis.
- ¹⁴ VetCare Multiparameter Monitor V9233B, B. Braun Vet Care, Rubí, Barcelona, Spain.
- ¹⁵ Quick Test Canine XM. Alvedia, Limonest, France.
- ¹⁶ Certofix Duo, B. Braun Vet Care.

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