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# Prognostic Factors for Mortality and Thromboembolism in Canine Immune-Mediated Hemolytic Anemia: A Retrospective Study of 72 Dogs

Anthony P. Carr, David L. Panciera, and Linda Kidd

Medical records of 72 dogs diagnosed with immune-mediated hemolytic anemia (IMHA) were reviewed to find risk factors for the disease, for mortality, and for thromboembolism. Coagulation data of 32 patients were evaluated for mortality or thromboembolism risk factors. Cocker Spaniels were at increased risk for IMHA ($P = .012$). Timing of vaccination was not associated with development of IMHA. PCV ranged from 5 to 33%, with a mean of 16 ± 5%. Autoagglutination was present in 42% of the dogs. Platelet counts (n = 60) varied from 3,000 to 793,000/μL (mean, 160,117 ± 133,571; median, 144,000). Thrombocytopenia (platelet count, <200,000/μL) was present in 70% of the dogs, with severe thrombocytopenia (platelet count, <50,000/μL) being present in 22%. One-step prothrombin time (OSPT) was prolonged in 28% of the dogs tested, and activated partial thromboplastin time (APTT) was prolonged in 47% of the dogs tested. Fibrin(ogen) degradation products (FDPs) were detected in 16 of 28 dogs tested (57%). Disseminated intravascular coagulation (DIC) was diagnosed in 10 of 31 (32%) dogs and was suspected in 8 dogs. Thromboemboli were found in 20 of 25 dogs given postmortem examinations. Mortality rate was 58%. Thrombocytopenia ($P = .008$) and serum bilirubin concentration of >5 mg/dL ($P = .015$) were risk factors for mortality, and hypoalbuminemia approached significance ($P = .053$). Severe thrombocytopenia ($P = .046$), serum bilirubin concentration of >5 mg/dL ($P = .038$), and hypoalbuminemia ($P = .016$) were risk factors for thromboembolism. On evaluation of continuous data, decreased platelet count ($P = .057$), increased bilirubin ($P = .062$), and decreased albumin ($P = .054$) approached significance for decreased survival. A higher risk for thrombosis was found with increased alkaline phosphatase (ALKP) ($P = .042$), increased bilirubin ($P = .047$), and decreased albumin ($P = .012$).

**Key words:** Disseminated intravascular coagulation; Hypoalbuminemia; Icterus; Thrombocytopenia; Vaccination.

Diagnosis of immune-mediated hemolytic anemia (IMHA) is based on identifying the combination of immune-mediated red blood cell (RBC) targeting (spherocytes, autoagglutination, and positive direct Coombs' test) with anemia and signs of hemolysis (hyperbilirubinemia, bilirubinuria, hemoglobinemia, or hemoglobinuria). IMHA can occur secondary to a variety of conditions, including systemic lupus erythematosus, neoplasia, and blood parasites, as well as administration of certain drugs. The majority of patients are considered idiopathic.

IMHA continues to be a therapeutic challenge in small animal practice. Immunoglobulin or complement coating of RBCs leads to lysis or phagocytosis. Mortality up to 70% has been reported and often is associated with thromboembolism.[1] A number of retrospective studies have attempted to identify prognostic and risk factors associated with IMHA.[1–6] Gender- and breed-related increased risk for IMHA has been documented in these studies. Icterus also seems to be an important risk factor for mortality in most studies.

Pulmonary thromboembolism (PTE) has been identified commonly in dogs with IMHA, and thrombi also can be found in other organs.[3] The etiology of thromboembolism in IMHA remains unclear. The primary factors involved in the pathogenesis of thrombosis, as defined by Virchow's triad, are as follows: changes in blood flow, in the balance of procoagulatory and anticoagulatory substances in the blood, and in vessel walls. Multiple hemostatic abnormalities have been reported in dogs with IMHA. The meaning of these abnormalities with regard to outcome or thromboembolism was not determined.[7]

The purpose of this study was to provide additional information about prognostic and risk factors for IMHA and thromboembolism in dogs. Vaccination data also were assessed to determine whether a temporal relationship existed between the development of IMHA and recent vaccination.

## Materials and Methods

### *Selection of Patients*

Medical records of the University of Wisconsin Veterinary Medicine Teaching Hospital from 1987 to 1995 were searched for cases of IMHA. A total of 112 cases diagnosed as IMHA were reviewed. Inclusionary criteria for IMHA included anemia (PCV, <34%) and one of the following: persistent autoagglutination, positive direct antiglobulin test (Coombs' test with immunoglobulin G or M [IgG or IgM] or complement [C3]), or regenerative anemia (reticulocytes, >60,000/μL) with moderate to marked spherocytosis.[3] In addition, evidence of hemolysis (hyperbilirubinemia, bilirubinuria, hemoglobinemia, hemoglobinuria, or spherocytosis) had to be present. Cases were excluded if an underlying disease process was recognized or if the inclusionary criteria were not met. Specific reasons for elimination from further evaluation included the presence of neoplasia (n = 7), incomplete records (n = 5), dirofilariasis (n = 1), and failure to fulfill study criteria with the data available (n = 27). To provide a control population for vaccine data, the numeric medical records before and after the case number of the IMHA patients were evaluated.

*From the Small Animal Clinical Sciences, Western College of Veterinary Medicine, Saskatoon, SK, Canada (Carr); the Department of Small Animal Clinical Sciences, Veterinary Teaching Hospital, Virginia-Maryland Regional College of Veterinary Medicine, Blacksburg, VA (Panciera); and the Department of Medical Sciences, School of Veterinary Medicine, University of Wisconsin, Madison, WI (Kidd).* *Previously presented in part at the 14th ACVIM Forum in San Antonio, TX, 1996.*

*Reprint requests: Anthony Carr, DMV, DACVIM, WCVM-SACS, University of Saskatchewan, 52 Campus Avenue, Saskatoon, SK, Canada S7N 5B4; e-mail: endovet@juno.com.*

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### *Data Analysis*

The gender and breed of affected dogs were compared to all dogs without IMHA in the hospital population during the same period. Information on the University of Wisconsin-Madison canine hospital population was obtained from the Veterinary Medical Data Base at Purdue University. The data gathered on dogs with IMHA, using values obtained at initial presentation, included age, vaccination status, PCV, presence of autoagglutination, direct Coombs' test result, platelet count, white blood cell (WBC) count, segmented neutrophil count, band neutrophil count, alanine aminotransferase (ALT) activity, alkaline phosphatase (ALKP) activity, albumin concentration, bilirubin concentration, one-step prothrombin time (OSPT), activated partial thromboplastin time (APTT), and fibrin(ogen) degradation products (FDPs). The number of transfusions (whole blood or packed red cells) given also was evaluated to determine whether a relationship to survival or development of thrombosis was present. If the patient had been treated with corticosteroids for 48 hours before presentation, values for ALT and ALKP activity were excluded from evaluation. If a transfusion had been given before presentation, hemostasis values were excluded from evaluation. The diagnosis of disseminated intravascular coagulation (DIC) was suspected if 2 of the following were present: thrombocytopenia (<200,000/μL), FDPs >10 μg/mL, and prolongation of one or both coagulation tests (OSPT and APTT) >25% of the control value. If all 3 criteria for DIC were met, it was considered a definite diagnosis. Death or euthanasia was considered related to IMHA if it occurred during the initial hospitalization or after discharge if it was associated with IMHA or a complication thereof (eg, failure to control disease and death resulting after sudden onset of dyspnea). Postmortem examination results were reviewed in 25 animals.

### *Laboratory Methods*

Values for WBC count, RBC count, and RBC indices were determined by an electronic cell counter.[a] Platelet counts were determined by standard manual methods.[b] Leukocyte differential counts and RBC morphology were determined by standard techniques. Autoagglutination was considered present when microscopic agglutination persisted after dilution with saline solution. The direct Coombs' test was performed with a polyvalent canine antiglobulin (IgG, IgM, or C3).[c] Serial 2-fold dilutions were made with a 30-minute incubation period at 37°C and at room temperature. FDPs were assayed with a latex agglutination kit[d] and were reported as <10, 10–40, or >40 μg/mL. OSPT and APTT were assayed with either a fibrometer[e] or an automated centrifugal analyzer.[f] Serum chemistries were determined by standard techniques.[g]

### *Statistical Analysis*

Pearson's $\chi^2$ test or the Fisher exact test was used to determine the association of mortality and confirmed thromboembolism with the following factors: autoagglutination, Coombs' test status, severe thrombocytopenia (<50,000/μL), thrombocytopenia (<200,000/μL), prolonged OSPT, prolonged APTT, prolongation of both OSPT and APTT, presence of FDPs, presence of confirmed or suspected DIC, administration of transfusions, bilirubin >5 mg/dL, and hypoalbuminemia (<2.7 g/dL). The Student's *t*-test was used when continuous data were analyzed (eg, relationship between mortality and thromboembolic complications to PCV, WBC count, segmented neutrophil count, band neutrophil count, platelet count, ALT activity, ALKP activity, bilirubin concentration, and albumin concentration). Time from vaccination to onset of IMHA was compared to time from vaccination to presentation in the vaccine control group by the Kolmogorov-Smirnov test. A rank correlation coefficient was used to determine if there was an association between ALKP activity and bilirubin concentration. Statistical significance was considered present at $P < .05$, and a trend toward significance was considered present at $P = .10$ to .05.

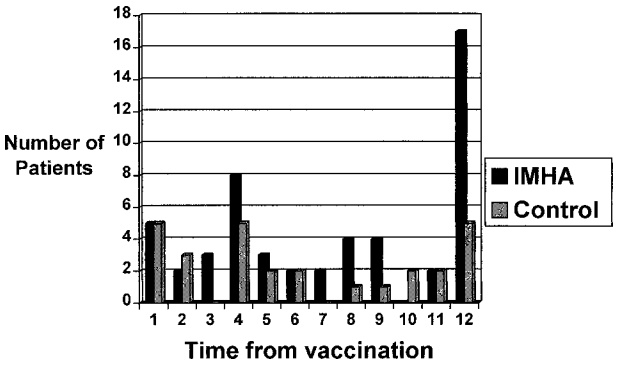


**Fig 1.** Time from vaccination (months) to onset of immune-mediated hemolytic anemia (IMHA) and time from vaccination to presentation in the control group. The last group includes dogs that were vaccinated ≥12 months ago ($P = .79$).

## Results

Seventy-two dogs were included in the study, and 28 different breeds were represented. The affected dogs represented 0.35% of the hospital's canine patient population. Only Cocker Spaniels were overrepresented when compared to the general hospital population (n = 9; $P = .012$). Gender distribution was 15% (n = 11) female, 54% (n = 39) female neutered, 11% male (n = 8), and 19% male neutered (n = 14). In relation to the hospital population, females were markedly overrepresented ($P = .011$) in comparison to males, spayed females were markedly overrepresented in comparison to intact females ($P = .01$), neutered animals were markedly overrepresented in comparison to intact animals ($P < .001$), and castrated males were overrepresented in comparison to intact males but not significantly ($P = .057$). Age ranged from 1 to 13 years with a mean of 6.8 ± 3.1 years.

Vaccination data were available for 52 of the dogs with IMHA. In the vaccine control group, 33 dogs could be evaluated, but the rest of the records were excluded because they belonged to other species or vaccine data were not available. Four dogs in the control group had not been vaccinated. Comparison of time from vaccination to onset of IMHA and time from vaccination to presentation in the control group failed to show a significant difference in the distributions when the 4 unvaccinated dogs were included in the ≥12-month postvaccination group ($P = .79$) or when they were left out of the statistical analysis ($P = .74$) (Fig 1).

Anemia was present in all dogs, with PCV ranging from 5 to 33% (mean, 16 ± 5%). Spherocytes were seen in 94% of the patients (n = 68; 14 mild, 24 moderate, and 30 marked). Autoagglutination was present in 42% of the dogs (n = 30). Table 1 gives the data on selected CBC parameters for the patient population. Thrombocytopenia (platelet count, <200,000/μL) was present in 70% of the dogs (42 of 60), with severe thrombocytopenia (platelet count, <50,000/μL) present in 22% of the dogs (13 of 60). The direct Coombs' test was positive in 33 of 43 patients tested (77%). Serum chemistry results (Table 2) were evaluated for the majority of the patients.

Hemostatic values were determined in 32 dogs. OSPT

**Table 1.** Selected CBC parameters in patient population.

| Parameter | No. Patients | Reference Range | Mean ± Standard Deviation | Median | Range |
|---|---|---|---|---|---|
| White blood cell count | 70 | 5,000–17,000/μL | 30,560 ± 15,969/μL | 27,400/μL | 7,700–67,800/μL |
| Segmented neutrophils | 70 | 3,000–12,000/μL | 23,594 ± 12,804/μL | 21,520/μL | 4,774–53,562/μL |
| Band neutrophils | 70 | 0–300/μL | 2,107 ± 2,590/μL | 1,351/μL | 0–14,525/μL |
| Platelet count | 60 | 200,000–500,000/μL | 160,117 ± 133,571/μL | 144,000/μL | 3,000–793,000/μL |

was prolonged in 28% of the dogs (9 of 32). APTT was prolonged in 47% of the dogs (15 of 32). All dogs with prolonged OSPT also had prolonged APTT. FDPs were detected in 16 of 28 dogs tested (57%), with 6 dogs having concentrations of 10–40 μg/dL and 10 having concentrations of >40 μg/dL. On the basis of the diagnostic criteria listed above, DIC was suspected in 18 of 31 (58%) dogs with sufficient data collected to allow a diagnosis to be made. In 10 of these dogs, all 3 criteria were consistent with a definitive diagnosis of DIC. Transfusions were given to 40 dogs (55%); only 1 dog received a transfusion before presentation. Twenty-four dogs received only 1 transfusion, 12 received 2 transfusions, and 4 received 3 transfusions.

Mortality rate for the 72 dogs was 58% (42 of 72). Nineteen dogs died, and 23 were euthanized. Postmortem examinations were performed on 25 dogs. Thromboemboli were found in 20 (80%) of the dogs given postmortem examinations. Thromboemboli were located in the lungs (9), heart (6), liver (4), spleen (8), kidney (8), and pituitary gland (2). In 10 dogs, emboli were found in multiple organs.

Statistically significant factors associated with mortality were thrombocytopenia ($P = .008$) and serum bilirubin concentration of >5 mg/dL ($P = .015$), and hypoalbuminemia approached significance ($P = .053$). Statistically significant factors associated with increased risk for thromboembolism included severe thrombocytopenia ($P = .046$), serum bilirubin concentration of >5 mg/dL ($P = .038$), and hypoalbuminemia ($P = .016$). Evaluation of continuous data revealed that decreased platelet count ($P = .057$), increased bilirubin concentration ($P = .062$), and decreased albumin concentration ($P = .054$) approached significance with regard to decreased survival. With regard to thrombosis, increased ALKP activity ($P = .042$), increased bilirubin concentration ($P = .047$), and decreased albumin concentration ($P = .012$) were markedly associated with a higher risk for thrombosis. A correlation between bilirubin concentration and ALKP activity also was found to be significant ($P = .002$).

## Discussion

Breed and gender predisposition may exist for IMHA. Poodles,[8] Cocker Spaniels,[1,4,8,9] Irish Setters,[8] English Springer Spaniels,[1,4] and Collies[4] have been identified to be at higher risk for IMHA. In our study, only Cocker Spaniels were overrepresented. Generally, females are considered to be at higher risk for IMHA than males.[10,11] Neutering has been considered a potentially predisposing factor. Although spayed females were reported to have a statistically higher chance of developing IMHA than intact females, this predisposition was no longer evident when the population characteristics were corrected for age.[11] Our data were not corrected for age differences in neutering status.

A close association between vaccination and onset of IMHA was found in one report with 25% of the dogs with IMHA having been vaccinated within 1 month of onset of the disease.[5] That report also showed that animals with vaccine-associated IMHA tended to respond more poorly to treatment than dogs not having been recently vaccinated. An association between vaccination and IMHA was not identified in our study. Approximately 10% of affected dogs in our study had been vaccinated within 1 month of presentation for IMHA. In other reports, between 2 and 4% of the patients had been vaccinated within 2 weeks of developing IMHA.[1,4] Given our data and that of previous studies, the association between vaccination and IMHA remains unproven.

In the present study, low serum albumin concentrations were associated with a markedly greater risk of thrombo-

**Table 2.** Chemistry values in patient population.

| Assay | No. Patients | Reference Range | Mean ± Standard Deviation | Median | Range |
|---|---|---|---|---|---|
| Alanine transferase | 55 | 0–79 U/L | 200 ± 556 U/L | 44 U/L | 3–3,335 U/L |
| Alkaline phosphatase | 56 | 0–166 U/L | 361 ± 579 IU/L | 168 IU/L | 14–3,875 IU/L |
| Albumin | 62 | 2.5–4.0 mg/dL | 2.8 ± 0.5 mg/dL | 2.8 mg/dL | 1.6–4.4 mg/dL |
| Bilirubin | 62 | 0.0–0.6 mg/dL | 8.2 ± 17.6 mg/dL | 1.4 mg/dL | 0.1–54.6 mg/dL |

embolism, and they approached statistical significance with regard to mortality. Hypoalbuminemia may be a result of the acute phase reaction, and lower albumin concentrations may signify greater severity of disease.[12] Impaired hepatic function may lead to decreased production of albumin. Many of the patients in our study had severe thrombocytopenia, and albumin loss could have occurred through hemorrhage. All of these factors would be consistent with hypoalbuminemia being an indicator of more serious disease. Although hypoalbuminemia is predictive of poor outcome in ill humans, independent of the underlying cause, it is unknown whether it has a specific pathophysiologic role.[12] Instead, it may be a reflection of general health. The nature of the association between thromboembolism and hypoalbuminemia is uncertain. Increased platelet reactivity to adenosine diphosphate in vitro has been identified in hypoalbuminemic nephrotic dogs.[13] These abnormalities were corrected by the addition of albumin to the platelets. Other studies suggest that hyperaggregability in nephrotic syndrome is multifactorial and not just a result of decreased albumin concentration.[14,15]

Icterus occurs commonly in dogs with IMHA. Icterus occurs because hepatic bilirubin clearance is reduced in hemolytic disease, and bilirubin turnover is increased.[16] In some animals with fulminant hemolysis, the rate of bilirubin production is increased in comparison to animals with liver disease, but in the majority of animals, its production is similar to that observed in patients with liver disease.[16] In severe anemia, hypoxia can induce severe centrizonal hepatic necrosis, which results in impaired liver function.[16] Hyperbilirubinemia (serum bilirubin concentration, $>10$ mg/dL) previously has been identified as a risk factor for mortality and thromboembolism in IMHA.[1,3,4] Results of our study are in agreement with these findings. A bilirubin concentration of $>5$ mg/dL at admission was associated with markedly increased mortality and risk of thromboembolism. The continuous data evaluation also indicated significance with regard to hyperbilirubinemia and thromboembolism and approached significance with regard to hyperbilirubinemia and mortality. The increased mortality with hyperbilirubinemia has been attributed to an increased rate of hemolysis and therefore the presence of severe IMHA.[3,4] In addition, hyperbilirubinemia could be associated with concurrent hepatic disease.[4] Increased bilirubin concentrations might be associated with more severe IgM and complement-associated disease, leading to more fulminant intravascular hemolysis and increased intravascular liberation of procoagulant RBC membranes.[3] An additional pathologic mechanism may be the generation of thrombi in the liver. In our study, 16% of the dogs given postmortem examinations had evidence of intrahepatic thrombosis, and all of the affected dogs were icteric.

The association between thromboembolism and high ALKP activity found in this study has not been documented previously. Dogs that had been pretreated with corticosteroids for $>48$ hours were excluded from evaluation of liver enzyme activities in the present study because of the confounding effects of these medications. High ALKP activity has been identified as a risk factor for increased mortality in dogs with IMHA.[1] Patients pre-treated with corticosteroids apparently were not excluded from this previous study, unlike the patients in our study. Bilirubin concentration and ALKP activity were significantly correlated, and increased ALKP activity could have occurred as a consequence of the same factors that caused icterus.

The majority of dogs in our study were transfused during treatment for IMHA. A high number of transfusions has been associated with greater risk of pulmonary thromboembolism in dogs with IMHA.[3] This relationship was not evident in our study, and other studies also have failed to show a correlation between transfusions and decreased survival.[4,9] The use of transfusions in immunohemolytic disease has been a source of controversy. Generally, patients exhibiting signs of acute fulminant hemolysis or progressive severe anemia should be considered for transfusion.[17] The frequency of adverse hemolytic reactions after transfusion in humans with IMHA is low.[18]

Thrombocytopenia was seen in the majority of the patients in our study, and it was often severe. In IMHA, the decrease in platelet count could result from increased consumption because of DIC, increased loss through hemorrhage, or increased destruction by immune-mediated mechanisms. The presence of concurrent IMHA and immune-mediated thrombocytopenia (ITP), termed ''Evans' syndrome,'' was suspected in 12% of the dogs in a previous study.[4] The combination of IMHA and ITP has been shown to be associated with a poorer outcome than either ITP or IMHA alone.[10] Unfortunately, in the patient population of our study, the majority of dogs with severe thrombocytopenia did not have hemostatic testing performed, and it is difficult to determine if consumptive coagulopathy contributed to the decline in platelet count. Thrombocytopenia was associated with increased mortality, and severe thrombocytopenia was associated with increased risk of thrombosis in the patient population of our study. The explanation for these findings is speculative. Antiphospholipid antibodies (APA) are found in a large number of humans with idiopathic IMHA.[19] In a study of women with systemic lupus erythematosus, concentrations of APA were compared between patients with and without hemolytic anemia.[20] High APA concentrations were more common in patients with IMHA, and thrombocytopenia also was more common in this group. Whereas 63.7% of the patients with IMHA and thrombocytopenia had high APA titers, none of the patients with thrombocytopenia but without hemolysis had high APA titers. The association between APA and thrombosis in humans is well documented.[20] Concurrent hemolysis, thrombosis, and lupus anticoagulant (an APA) have been reported in a dog.[21] Unfortunately, testing for APA in veterinary medicine is not routine, and it is unknown whether APA played a role in the patients in our study.

Abnormal hemostasis was present in the majority of dogs tested. DIC was suspected in 58% and confirmed in 32% of the patients in our study that had adequate hemostasis testing performed to allow evaluation for DIC. In previous studies, 15%[9] to 19%[4] of affected dogs were suspected to have DIC. The presence of DIC (suspected or confirmed) was, however, not a risk factor for thrombosis or mortality in the patients of our study. The pathogenesis of DIC in IMHA may be multifactorial. Liberation of RBC stroma may be one trigger for DIC during hemolysis.[22] Administration of autologous hemolyzed erythrocytes to dogs led

to a hypercoagulable state and intravascular coagulation.[23] Tissue factor production and release by leukocytes are induced in vitro when erythrocytes are sensitized with alloantibodies.[24] Tissue factor is considered to have a central role in procoagulatory states such as DIC.[25] Free hemoglobin itself is not procoagulatory, but in combination with other substances, it may be a trigger for DIC. Purified free hemoglobin does not induce increased production of tissue factor by cultured endothelial cells unless endotoxin is added to the hemoglobin.[26] Production of tumor necrosis factor increased markedly more when mice were infused with free hemoglobin before endotoxin challenge than when they were given lipopolysaccharide alone.[27] With this model, it was also shown that hemoglobin infusion lipopolysaccharide challenge leads to markedly higher mortality.[28] Hemoglobin has also been show to enhance the binding of endotoxin to human endothelial cells with a resultant increase in tissue factor expression.[29] Given the ischemia induced by the severe anemia in some animals with IMHA and the administration of corticosteroids with their potentially disruptive effect on gastrointestinal mucosal integrity, endotoxin may play a procoagulatory role, especially when free hemoglobin is present. Administration of stroma-free hemoglobin solutions to primates resulted in DIC and multiple organ failure when minute amounts of endotoxin or stromal phospholipids were present.[22] However, a similar effect did not occur when the hemoglobin solution was highly purified. The presence of free hemoglobin also may predispose to a hypercoagulable state by binding nitric oxide (NO). NO is vital for vasodilatation and is a potent inhibitor of platelet aggregation. Even minute amounts of free hemoglobin will inactivate NO.[30] As a result, in dogs with IMHA, free hemoglobin may inactivate NO and result in increased platelet aggregation.

Mortality associated with IMHA has been high in most reports.[1–6,9] Reported mortality rates have varied partially as a result of the follow-up duration. In one study that followed dogs up to 1 year, a 70% mortality rate was found in association with IMHA.[1] In the patient population of our study, more dogs were euthanized than died. It is difficult in a retrospective study to determine if animals were euthanized because of the generally poor prognosis associated with the disease, monetary constraints, or severe illness. Even excluding the animals euthanized, mortality was >26%. Thromboembolic complications have been recognized as a clinically important factor in mortality associated with IMHA. Postmortem examination–confirmed pulmonary thromboembolism was present in 32% of the dogs treated for IMHA in one study.[3] In the patients of our study, thromboembolism was confirmed in 28% of the dogs and found in 80% of the dogs given postmortem examinations. Multiple organs were affected, possibly as a consequence of DIC.

Our study adds further information to what is already known about IMHA. Many questions, however, remain unanswered and could form the basis for further studies. It would be interesting to determine prospectively if there is a difference in outcome on the basis of the type of transfusion received (whole blood, packed RBCs, or hemoglobin substitutes), especially considering a recent study that implicated bovine hemoglobin solution in increased risk of death.[31] Thromboembolism was a common finding in the patients of our study and in those of other studies as well.[3] Treatments to prevent thrombosis should be prospectively examined, and efforts should be made to identify the reason or reasons for the hypercoagulable state seen in IMHA, which otherwise is rare in dogs. DIC seems to be common in IMHA, and treatment modalities for DIC should be evaluated with regard to mortality and thrombosis. Euthanasia is a confounding factor in mortality studies in dogs, and it would be useful to determine what factors lead clients to the decision of euthanasia.

## Footnotes

[a] Coulter S770 electronic cell counter, Beckman Coulter, Fullerton, CA
[b] Unopette methods, Becton-Dickinson, Rutherford, NJ
[c] Canine antiglobulin (Coombs' test), ICN Immunobiologicals, Lisle, IL
[d] Thrombo-Wellcotest latex agglutination kit, Wellcome Diagnostics, Dartford, UK
[e] Fibrometer, Becton-Dickinson, Rutherford, NJ
[f] ACL 300+ centrifugal analyzer, Beckman Coulter, Hialeah, FL
[g] Kodak Ektachem 500, Kodak, Rochester, NY

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