Prevalence and Mode of Inheritance of the Dal Blood Group in Dogs in North America

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Background: The Dal blood group system was identified a decade ago by the accidental sensitization of a Dal− Dalmatian with a Dal+ blood transfusion. Similar Dal-related blood incompatibilities have been suspected in other Dalmatians, Doberman Pinschers, and other breeds.

Objectives: To determine the prevalence and mode of inheritance of the Dal antigen expression in dogs.

Animals: A total of 1130 dogs including 128 Dalmatians, 432 Doberman Pinschers, 21 Shih Tzus, and 549 dogs of other breeds including 228 blood donors were recruited from North America between 2008 and 2015.

Methods: Prospectively, dogs were blood typed for Dal applying a gel column technique using polyclonal canine anti-Dal sera. Pedigrees from 8 typed families were analyzed.

Results: The prevalence of the Dal+ blood type varied between 85.6 and 100% in Dalmatians and 43.3−78.6% in Doberman Pinschers depending on geographical area. Dal− dogs were identified mostly in Dalmatians (15/128; 11.7%), Doberman Pinschers (183/432; 42.4%), and Shih Tzus (12/21; 57.1%), and sporadically in mixed-breed dogs (3/122; 2.5%). Lhasa Apsos (1/6) and Bichon Frises (1/3). Only 6/245 (2.4%) blood donors were found to be Dal−, including 5 Doberman Pinschers. The mode of inheritance of the Dal+ phenotype was determined to be autosomal dominant.

Conclusions and Clinical Importance: The high percentage of Dal− Doberman Pinschers, Dalmatians and Shih Tzus increases their risk of being sensitized by a blood transfusion from the common Dal+ donor. Extended Dal typing is recommended in those breeds and in dogs when blood incompatibility problems arise after initial transfusions.

Key words: Blood typing; Dog erythrocyte antigen; Hemolysis; Transfusion.
from the veterinary clinics of 3 Universities (University of Guelph, Ontario Veterinary College [OVC], University of Montreal [Centre Hospitalier Universitaire Vétérinaire [CHUV]], and University of Pennsylvania [PennVet]), dog shows, and private blood banks in Canada and the United States. Dogs recruited from the veterinary clinics were either sick dogs or healthy dogs admitted for screening of subclinical disorders or routine health evaluation.

**Dalmatians and Doberman Pinschers**

The majority of dogs recruited from OVC were asymptomatic Doberman Pinschers enrolled in a study of dilated cardiomyopathy. In addition to dogs recruited from the veterinary clinics, breeders were approached at dog shows to obtain blood samples from their Dalmatians and Doberman Pinschers. In order to establish the mode of inheritance of the Dal blood group system, some breeders were also asked to submit samples from families including dam, sire, and offspring. Most Dalmatians in the USA were recruited at the Dalmatian Club of America National Specialty show in Huron, Ohio, in 2015.  

**Shih Tzus.** After recognizing a blood incompatibility in a Dal—Shih Tzu at OVC, additional Shih Tzu dogs were recruited from that clinic.

**Dogs of other breeds and blood donors.** Canine blood donors (≥23 kg, 2–8 years old) were recruited from the 3 veterinary blood banks listed above as well as from private blood banks in Canada and the United States. Dogs of other breeds that were not blood donors were recruited from the 3 universities and represented either dogs in need of a blood transfusion or dogs with blood incompatibility after a prior transfusion, or left-over blood samples from PennVet or CHUV.

Information including the medical history, breed, color, sex, and age of dog was obtained, in addition to the DEA 1 type, official registration name and number, and geographical location of dog at time of collection when available. Dalmatian and Doberman Pinscher owners were asked whether their dog was already enrolled in a blood donor program; if so, the information was used for descriptive data of the blood donor group, but the individual dog remained within its specific breed group for statistical purposes. The study was approved by the institutional animal care and use committees of the universities of Guelph, Montreal, and Pennsylvania.

**Blood Samples**

Ethylene-diaminetetraacetic acid (EDTA)-anticoagulated blood samples were collected from the jugular or cephalic vein with owner consent, or represented left-over samples submitted to the universities’ clinical laboratories.

**Dal Blood Typing**

Dal blood typing was performed using neutral buffered gel column cards from Diamed\(^b\) and Ortho Clinical Diagnostics,\(^b,12,13\) Sera containing polyclonal anti-Dal antibody obtained after an accidental sensitization of a Dal—Doberman Pinscher from Tufts University in 2007\(^b\) and of a sensitized Dal—research Beagle from the University of Montreal in 2013 were used undiluted.\(^b,14\) Both sera were similarly active against the Dal antigen when compared to the serum from the original index Dal—Dalmatian.\(^b\)

Briefly, a 0.8% RBC suspension was prepared by adding 10 μL of packed and washed RBCs to 1 mL of low ionic strength saline solution.\(^b,12\) Fifty μL of this RBC suspension was placed in the chamber on top of the gel column in addition to 25 μL of anti-Dal serum, and then, the card was incubated at 37°C for 15 minutes.\(^b\) The gel column card was then centrifuged\(^b\) for 10 minutes, and the degree of agglutination was read.\(^b\) If the RBCs migrated to the bottom of the gel column, the result was negative, and the dog was typed as Dal—. If the RBCs were trapped on top or within the gel column, the results were positive and graded from 1+ to 4+.\(^15,16\)

**DEA 1 Blood Typing**

If the DEA 1 information was not already available from the medical record, dogs were also blood typed for DEA 1 using either commercially available gel column tests\(^b\) or, when they became unavailable in 2011, immunochromatographic strips,\(^b\) according to the manufacturer’s instructions.\(^b\) Both techniques use the same monoclonal anti-DEA 1 antibody.\(^b\)

**Detection of Dal Alloantibodies**

Plasma samples from Dal—dogs identified at PennVet, and from a Dal—Shih Tzu from OVC with transfusion-related incompatibilities, were examined for anti-Dal antibodies using the gel column technology and known Dal+ RBCs.\(^13,18\)

**Statistical Analysis**

The prevalence of the Dal+ blood type with a 95% confidence interval was estimated for selected breed groups with larger sample size and for which Dal—dogs were identified (i.e., Dalmatians, Doberman Pinschers, Shih Tzus, and other breeds) per geographical areas (Ontario [Canada], Quebec [Canada], and USA). For Dalmatians and Doberman Pinschers, 1 puppy per litter was randomly selected (using a pseudorandom number generator in SAS v.9.4)\(^i\) for prevalence estimations, and statistical adjustments were made for potential clustering of dogs within breeders and geographical regions.\(^k\) Therefore, 24 Dalmatian puppies from 5 litters and 63 Doberman Pinscher puppies from 14 litters were excluded from estimation of geographical prevalences. Because of its clinical importance, risk factors were evaluated for the Dal—phenotype. Multivariate exact logistic regressions\(^19\) were used to determine whether the Dal—blood type was significantly associated with sex, age, coat color, DEA 1 type, and geographical area and were performed separately for each breed with a sufficient sample size and in which Dal—dogs were detected. One dog per breeder was randomly selected for inclusion in these analyses. A forward selection procedure was used to build each model, using a \(P < .05\) as criteria for inclusion of variables (exact test).\(^i\) Pedigree analysis was built based on the Dal+ or Dal—type and was analyzed for simple Mendelian inheritance patterns.\(^20\)

**Results**

**Breeds and Demographics**

From 2008 to 2015, 1130 dogs were typed for Dal including 128 Dalmatians, 432 Doberman Pinschers, 21 Shih Tzus, and 549 dogs of other breeds. This included 228 non-Dalmatian and non-Doberman Pinscher blood donors from volunteer blood donor programs: CHUV and 2 associated local private blood banks (n = 69), OVC (n = 98), and PennVet, which also received samples from blood donors at Hemopet\(^m\) and the Ohio State University\(^n\) (n = 61). The 321 nonblood donor dogs represented various breeds in need of blood transfusions or from which left-over samples were available at PennVet or CHUV. The ages of all dogs considered together ranged from 1 month to 15 years. The description of the selected population for the prevalence study
after exclusion of randomly selected puppies is detailed in Table 1.

**Dal Type Gel Column Technique and Prevalence**

All Dal blood typing results using the gel column technology yielded easily interpretable agglutination reactions, with either no (grade 0) or strongly positive agglutination reactions (3+ or 4+) (Fig 1).

The prevalence of the Dal+ phenotype varied among breeds and geographical area (Tables 1 and 2). Dal− dogs were identified mostly in Dalmatians (12%), Doberman Pinschers (42%), Shih Tzus (57%), and few other breeds. All other purebred dogs were Dal+ except for 1 Bichon Frise and 1 Lhasa Apso. Three Dal− dogs were detected among 122 mixed-breed dogs (Table 2).

### Table 1. Prevalence with 95% confidence intervals (C.I.) of the Dal+ blood type in Dalmatians, Doberman Pinschers, Shih Tzus, and other breeds from various areas of North America.

| Origin                  | N  | Year of sample submission | Dal+ Prevalence (%) |
|-------------------------|----|----------------------------|---------------------|
| **Dalmatians**          |    |                            | Dal+ Prevalence (%) |
| Quebec, Canada          |    |                            | Dal+ Prevalence (%) |
| CHUV                    | 5  | 2014–2015                  | 4.4 100.0 47.8–100.0 |
| Breeder                 | 7  | 2013–2015                  | 2.6 100.0 59.0–100.0 |
| Ontario, Canada         |    |                            | Dal+ Prevalence (%) |
| OVC                     | 2  | 2010–2015                  | 3.0 100.0 15.8–100.0 |
| USA                     |    |                            | Dal+ Prevalence (%) |
| Breeder                 | 90 | 2015                       | 3.9 85.6 76.4–94.7  |
| **Doberman Pinschers**  |    |                            | Dal+ Prevalence (%) |
| Quebec, Canada          |    |                            | Dal+ Prevalence (%) |
| CHUV                    | 93 | 2013–2015                  | 4.5 59.1 48.5–69.2  |
| Breeder                 | 104| 2013–2015                  | 3.3 43.3 28.9–57.6  |
| Ontario, Canada         |    |                            | Dal+ Prevalence (%) |
| OVC                     | 158| 2008–2013                  | 5.5 72.2 64.5–79.0  |
| USA                     |    |                            | Dal+ Prevalence (%) |
| PennVet                 | 14 | 2015                       | 5.4 78.6 49.2–95.3  |
| **Shih Tzus**           |    |                            | Dal+ Prevalence (%) |
| Quebec, Canada          | 2  | 2014–2015                  | 11.5 100.0 15.8–100.0 |
| Ontario, Canada         |    |                            | Dal+ Prevalence (%) |
| OVC                     | 14 | 2008–2014                  | 9.0 21.4 4.7–50.8   |
| USA                     |    |                            | Dal+ Prevalence (%) |
| PennVet                 | 5  | 2015                       | 9.1 80.0 28.4–99.5  |
| **Dal Blood Type in Blood Donors**

Of the 228 non-Dalmatian and non-Doberman Pinscher blood donors 227 were Dal+, including commonly recruited breeds such as Greyhounds (n = 73), Labradors Retrievers (n = 23), German Shepherd Dogs (n = 18), and Golden Retrievers (n = 14). All nonblood donor dogs of these same 4 breeds were also Dal+ (Table 2). Only 1 Dal− mixed-breed blood donor was identified (at OVC). Of all the Doberman Pinschers tested, 16 had been enrolled in a blood donor program, and 5 of them were Dal+. Only 1 Dalmatian was already part of a blood donor program and was Dal+.

**Evaluation for Anti-Dal Alloantibodies**

No anti-Dal alloantibodies were detected in plasma of the 23 Dal− dogs tested without prior transfusion history. However, the plasma from the previously transfused Dal− Shih Tzu, found to be incompatible to regular donors, showed strong anti-Dal alloantibodies by the gel column method (4+).

**Risk Factor Analysis Related to Dal− Type**

Risk factors for Dal− blood type were examined for Dalmatians and Doberman Pinschers (Table 3). No variables were significantly different for Dal+ and Dal− Dalmatians. For Doberman Pinschers, Dal− blood type did not vary by sex, coat color, or DEA 1 status (P > .05 for all analyses), but varied significantly by geographical region; the probability of Dal− was significantly greater in Quebec compared to Ontario, Canada (odds ratio of 2.01 P = .01).

**Mode of Inheritance**

One Dalmatian and 7 Doberman Pinscher families comprised of 117 dogs (60 Dal+ and 57 Dal−) were...
studied (Table 4 and Fig 2). As the proportion of Dal+ phenotype did not vary significantly by sex in these families, or within the breeds (Table 3), an X-chromosomal mode of inheritance could be excluded. When both parents were Dal+, only Dal− offspring were found. Dal+ dogs bred with Dal− dogs produced more Dal+ than Dal− puppies (ratio 19:14). If both parents were Dal+, they produced all Dal+ offspring, except for 2 litters where 3 Dal− puppies were identified among 12 offspring. These observations support an autosomal dominant mode of inheritance for Dal antigen expression and the Dal+ type. In addition to these families, 4 litters including 12 offspring but missing 1 or both parents for the pedigree analysis showed distributions consistent with an autosomal dominant mode of inheritance.

Table 2. Percentage of Dal+ dogs in breeds represented by ≥20 individuals or in which Dal− dogs were identified in North America.

| Breed                  | Number of dogs | Dal+ | Dal− | Percentage of Dal+ (%) |
|------------------------|----------------|------|------|------------------------|
| Dalmatian              | 128            | 113  | 15   | 88.3                   |
| Doberman Pinscher      | 432            | 249  | 183  | 57.6                   |
| Shih Tzu               | 21             | 9    | 12   | 42.9                   |
| Bichon Frise           | 6              | 5    | 1    | 83.3                   |
| Lhassa Apso            | 3              | 2    | 1    | 66.7                   |
| Mixed-breed            | 122            | 119  | 3    | 97.5                   |
| German Shepherd Dog    | 34             | 34   | 0    | 100                    |
| Golden Retriever       | 32             | 32   | 0    | 100                    |
| Greyhound              | 85             | 85   | 0    | 100                    |
| Labrador Retriever     | 47             | 47   | 0    | 100                    |
| Othera                 | 220            | 207  | 0    | 100                    |

Breeds in which Dal− individuals were identified are presented in bold lettering.

*aBreeds (n) represented by less than 20 individuals and without any Dal− dog identified included the following: Great Dane (13), Standard Poodle (9), Maltese Terrier (9), Yorkshire Terrier (8), English Bulldog (7), Havane (7), Siberian Husky (7), Rottweiler (7), Boxer (6), Miniature Schnauzer (6), West Highland White Terrier (6), Bernese Mountain Dog (5), Chihuahua (5), American Cocker Spaniel (5), Dachshund (5), Newfoundland Retriever (5), Unknown (5), Airedale Terrier (4), American Pitbull Terrier (4), Australian Shepherd Dog (4), Hound (4), Australian Cattle Dog (3), Bouvier des Flandres (3), Bull Mastiff (3), Jack Russell Terrier (3), Samoyed (3), Beagle (2), Cavalier King Charles Spaniel (2), Flat Coated Retriever (2), Great Pyrenees (2), Irish Wolfhound (2), Kuvasz (2), Mastiff (2), Miniature Dachshund (2), Pug (2), Redbone Coonhound (2), Saint Bernard (2), Shar Pei (2), Tibetan Terrier (2), Vizsla (2), Weimaraner (2) and 1 each of Afghan Hound, Akita, Anatolian Shepherd Dog, Beauceron, Bloodhound, Border Collie, Borzoi, Bull Terrier, Bull-dog, Cairn Terrier, Catahoula Leopard, Chinese Crested, Chow Chow, Collie, Dogue de Bordeaux, English Cocker Spaniel, English Mastiff, English Shepherd Dog, English Springer Spaniel, Griffon Korthal, Italian Greyhound, Japanese Mastiff, Labradoodle, Leonberger, Miniature Pinscher, Norwich Terrier, Old English Sheepdog, Papillon, Pekingese, Pembroke Welsh Corgi, Red Tick Hound, Rhodesian Ridgeback, Saluki, Schipperke, Schnauzer, Shetland Sheepdog, Soft Coated Wheaten Terrier, Spanish Water Dog, Staffordshire Bull Terrier, Whippet.

Table 3. Descriptive statistics of evaluated risk factors, including sex, age, coat color, DEA 1 status, and region, for Dal− status. For each breed, 1 dog was randomly selected per breeder. For some dogs, the information was not available.

| Evaluated Risk Factor | Dalmatian | Doberman Pinschers |
|-----------------------|-----------|-------------------|
| Sex                   | n | % Dal− | n | % Dal− |
| Male                  | 31 | 9.7 | 158 | 34.2 |
| Female                | 28 | 3.6 | 116 | 32.8 |
| Age                   |   |       |   |       |
| <1 year               | 13 | 23.1 | 18 | 50.0 |
| 1-5 years             | 37 | 5.4 | 140 | 32.1 |
| >5 years              | 12 | 0.0 | 122 | 33.6 |
| Coat color            |   |       |   |       |
| Black white           | 46 | 8.7 | NA | NA |
| Liver white           | 13 | 7.7 | NA | NA |
| Black                 | NA | NA | 63 | 47.6 |
| Red                   | NA | NA | 27 | 51.9 |
| Isabellla             | NA | NA | 5 | 40.0 |
| Blue                  | NA | NA | 2 | 0.0 |
| DEA 1                 |   |       |   |       |
| Positive              | 59 | 8.5 | 52 | 36.4 |
| Negative              | 1 | 0.0 | 111 | 60.4 |
| Region                |   |       |   |       |
| Ontario (Can)         | 2 | 0.0 | 158 | 27.8 |
| Quebec (Can)          | 11 | 0.0 | 108 | 44.4 |
| USA                   | 49 | 10.2 | 14 | 21.4 |

*NA, not applicable.

Table 4. Proportion of Dal+ and Dal− offspring depending on the Dal status of matings (Dal+ × Dal+, Dal+ × Dal− or Dal− × Dal−).

| Matings               | Number of offspring (n) |
|-----------------------|-------------------------|
| Dal blood type of parents | Dal+ | Dal− |
| Dal+ × Dal+          | 3 | 15 | 3 |
| Dal+ × Dal−          | 8 | 19 | 14 |
| Dal− × Dal−          | 5 | 0  | 23 |
| Total                | 16 | 34 | 40 |

Discussion

The Dal blood group was initially described in an anemic Dal− Dalmatian that was incompatible with other dogs except to several Dalmatians, but a larger survey was required to establish its prevalence in Dalmatians as well as in other breeds.12 In the present study, using a gel column technology and polyclonal anti-Dal antibodies, 1130 dogs from North America were blood typed. Only strong Dal+ of Dal− typing reactions, and no naturally occurring anti-Dal antibodies, in nontransfused Dal− dogs, were detected. This study identified Dal− dogs in breeds other than Dalmatians and research Beagles,12,14 notably in Doberman Pinschers and Shih Tzus, but also in Lhassa Apsos,
The clinical importance of Dal in Doberman Pinschers might be considerable given that 42% were Dal- in this study sample. In addition, the high prevalence of von Willebrand disease (vWD) in Doberman Pinschers creates a particular challenge for this breed. This primary hemostatic disorder puts Doberman Pinschers at higher risk of bleeding which can lead to the need for multiple transfusions, including fresh whole blood, packed RBC, fresh-frozen plasma, or cryoprecipitate, increasing their risk of being sensitized to the Dal antigen. Unfortunately for Dal- dogs, there is a scarcity of Dal- blood donors (1 mixed-breed dog and 5 Doberman Pinschers among all typed donors) based upon this survey of blood donors and the original publication on Dal.12

Doberman Pinschers and Dalmatians are not commonly recruited as blood donors.12,26 In the original Dal report, of the 55 privately owned canine blood donors, only 1 was a Doberman Pinscher and none were Dalmatians.12 Similarly, in a study including 60 non-Greyhounds screened for DEA 1, no Dal- dogs were identified. Doberman Pinscher and no Dalmatians were investigated.26 In addition to Greyhounds, the most common purebred dogs were Borzois, German Shepherd Dogs, Golden Retrievers, and Labrador Retrievers.12,26 In the current study, only 1 Dalmatian and 16 Doberman Pinschers were enrolled active blood donors. The most common purebred dogs recruited as blood donors were multiallelic (≥4) autosomal dominant blood group system for DEA 1 was reported, after a heritable pattern of varied antigenic expression was observed, ranging from a complete lack (DEA 1-) to various degrees of positivity (agglutination reactions ranging from 2+ to 4+).20 In the current study, all Dal typing results yielded either a clear negative (0) or a strong positive (3+ or 4+) agglutination reaction, supporting a simpler 2 allele model with the Dal+ allele being dominant over the Dal- allele.

This study identified numerous Dal- dogs in Dalmatians as well as in Doberman Pinschers. Moreover, we also discovered several Dal- Shih Tzus while investigating a blood incompatibility in a recently transfused anemic dog. Although only a small number of Lhasa Apsos and Bichon Frises were typed, 1 Dal- of each breed were identified, which deserves further prevalence investigation. According to the International Federation of Cynology, both Shih Tzus and Lhasa Apsos originate from Tibet and likely share some common ancestry, but the others have no close ancestors and thus the Dal- blood type might be far more prevalent. In addition, 2 Dal- dogs were identified after screening 100 research Beagles.14 These findings suggest a more ancestral mutation, and thereby, more breeds with Dal- dogs are likely to be found.

 Whereas all Dalmatians recruited in Canada were Dal+ (n = 26), the prevalence of the Dal+ phenotype in Dalmatians (n = 90) in the USA was 85.6%. In comparison, the original Dal survey conducted in 2005 showed a similar ratio with 5 Dal- of 26 Dalmatians (80.8%) recruited from various geographical areas in the USA (Pennsylvania, New York, Illinois, and Texas) and some dogs were known to be related.12

The proportion of Dal+ and Dal- individuals did not vary significantly by sex. In addition, Dal- parents produced only Dal- offspring, and Dal+ offspring were rare if both parents were Dal+. Consequently, the pedigree analyses revealed an autosomal dominant mode of inheritance of the Dal+ phenotype similar to what has been found with other canine blood groups investigated to date.6,20-22 In 1953, inheritance of canine blood types A, B, C, and D (which likely correspond to DEA 1, 3, 4, and 5, respectively, using the current international nomenclature) was studied, which showed that blood groups are inherited as simple Mendelian dominants without evidence of association.1,21 Thereafter, a dominant inheritance was suggested for several other canine RBC antigens for which relations were not established with internationally recognized DEA, but no formal pedigree analyses were presented.22 Most recently, a
Greyhounds, Labrador Retrievers, German Shepherd dogs, and Golden Retrievers, all of which were Dal− (as were all dogs of these same breeds which were not blood donors). The near absence of Dalmatians as blood donors might be due to their weight generally being borderline for recruitment criteria (>23 kg recommended when using standard collection bags) and their perceived apprehensive demeanor in veterinary clinics. The low number of Doberman Pinschers as blood donors might be due to the high prevalence of vWD, the associated cost of screening, and the potential occult cardiomyopathy in the breed. The scarcity of Doberman Pinschers and Dalmatians as blood donors amplifies the rarity of Dal− blood in blood banks leading to the almost certain sensitization of Dal− dogs and consequently risk of acute hemolytic transfusion reaction if subsequent transfusions are required. Thus, the specific recruitment of Dal− Doberman Pinschers and Dalmatians as blood donors might be desirable.

When discovered, Dal was thought to be a high-incidence antigen, as the incidence of Dal+ was >90% in the breed and believed to be maternally inherited in 1 breed and in only a few individuals of that breed. According to the International Society of Blood Transfusion (ISBT) in human medicine, the criteria for inclusion as a high-incidence antigen are as follows: (1) an incidence of >90% in most populations tested, but usually >99%; (2) distinction from all other high-incidence specificities; and (3) demonstration that the antigen is lacking in at least 2 siblings, giving evidence that the negative phenotype is genetically determined. Studies identifying high-incidence antigens usually report only a few individuals lacking the antigen. In this study, the prevalence of the Dal− minor allele was >10% in several breeds and thus the Dal antigen seems to be a true blood group system rather than a high-incidence antigen.

Given the dominant inheritance pattern and the scarcity of Dal− dogs within the general population of dogs, the most promising sources of compatible blood for Dal− recipient dogs would be in Utah, and thus might remain limited in supply. For Dal typing, both tube and gel column techniques can be used. The gel column technology is easier to interpret, but requires kits and equipment. With DEA 1, the production of a monoclonal antibodies and commercial typing kits extended the availability and standardization of DEA 1 typing. In that perspective, production of monoclonal antibodies could increase the availability of Dal blood typing in dogs and would facilitate its commercial availability.

### Conclusion

This study showed that the Dal blood type has an autosomal dominant mode of inheritance and identified several breeds with Dal− dogs in addition to the previously reported Dalmatians, notably Doberman Pinschers and Shih Tzus. Because most purebred breeds tested are Dal+, including all Greyhounds, Golden and Labrador Retrievers, and German Shepherd dogs, Dal− blood donors are rare and Dal− dogs are at high risk of transfusion incompatibility when in need of blood on more than 1 occasion. In addition to the current recommendation to cross-match when dogs have been previously transfused, extended Dal typing, although limited by its commercial availability, is recommended in Dalmatians, Doberman Pinschers, and Shih Tzus, particularly when requiring transfusions over more than a few days.
Footnotes

a DiaMed AG, Cressier FR, Switzerland
b ID-MTS Buffered Cards, Ortho Clinical Diagnostic, Ontario, Canada
c Goulet S, Blais MC, Abrams-Ogg ACG. Prevalence of the Dal blood type in Doberman Pinschers and in canine blood donors. J Vet Intern Med 2014;28:1054
d LISS ID-Diluent “Vet 1”, DiaMed AG, Switzerland
e Antibody Enhancement Solution, Ortho Clinical Diagnostic, Ontario, Canada
f ID-incubator 37S I, DiaMed Microtyping System, Switzerland
g DiaMed-Vet ID Card DEA 1.1, DiaMed AG, Switzerland
h DEA 1 Alvedia lab test, Alvedia, Lyon, France
i RANUNI function, SAS statistical software v.9.4, SAS Institute Inc. Cary, NC
j SURVEYFREQ procedure, SAS statistical software v.9.4, SAS Institute Inc. Cary, NC
k LOGISTIC procedure, SAS statistical software v.9.4, SAS Institute Inc. Cary, NC
l Hemopet, Garden Grove, CA
m Veterinary Medical Center, Columbus, OH
n Federation Cynologique Internationale, http://www.fci.be/en/

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Conflict of Interest Declaration: Authors declare no conflict of interest.

Off-label Antimicrobial Declaration: Authors declare no off-label use of antimicrobials.

References

1. Vriesendorp HM, Albert ED, Templeton JW, et al. Joint report of the Second International Workshop on Canine Immunogenetics. Transplant Proc 1976;8:289–314.
2. Vriesendorp HM, Westbroek DL, D’Amaro J, et al. Joint report of 1st International Workshop on Canine Immunogenetics. Tissue Antigens 1973;3:145–163.
3. Hohenhaus AE. Importance of blood groups and blood group antibodies in companion animals. Transfus Med Rev 2004;18:117–126.
4. Giger U. Blood typing and crossmatching to ensure blood compatibility. In: Bonagura JD, Twedt DC, eds. Kirk’s Current Veterinary Therapy, 15th ed. St.-Louis, MO: Elsevier Saunders; 2014:e143–e147.
5. Ottenberg R, Kaliski DJ, Friedman SS. Experimental agglutinative and hemolytic transfusions. J Med Res 1913;28:141–163.
6. Swisher SN, Young LE. The blood grouping systems of dogs. Physiol Rev 1961;41:495–520.
7. Young LE, Ervin DM, Yule CL. Hemolytic reactions produced in dogs by transfusion of incompatible dog blood and plasma. I. Serologic and Hematologic Aspects. Blood 1949;4:1218–1231.
8. Giger U, Gelens CJ, Callan MB, et al. An acute hemolytic transfusion reaction caused by dog erythrocyte antigen 1.1 incompatibility in a previously sensitized dog. J Am Vet Med Assoc 1995;206:1358–1362.
9. Callan MB, Jones LT, Giger U. Hemolytic transfusion reactions in a dog with an alloantibody to a common antigen. J Vet Intern Med 1995;9:277–279.
10. Melzer KJ, Wardrop KJ, Hale AS, et al. A hemolytic transfusion reaction due to DEA 4 alloantibodies in a dog. J Vet Intern Med 2003;17:931–933.
11. Swisher SN, Young LE, Trabold N. In vitro and in vivo studies of the behavior of canine erythrocyte-isoantibody systems. Ann N Y Acad Sci 1962;97:15–25.
12. Blais MC, Berman L, Oakley DA, et al. Canine Dal blood type: A red cell antigen lacking in some Dalmatians. J Vet Intern Med 2007;21:281–286.
13. Kessler RJ, Reese J, Chang D, et al. Dog erythrocyte antigens 1.1, 1.2, 3, 4, 7, and Dal blood typing and cross-matching by gel column technique. Vet Clin Pathol 2010;39:306–316.
14. Goulet S, Blais MC. Characterization of anti-Dal alloantibodies following sensitization of two Dal-negative dogs. Vet Pathol 2017; doi: 10.1177/0300985816688746.
15. Giger U, Stieger K, Palos H. Comparison of various canine blood-typing methods. Am J Vet Res 2005;66:1386–1392.
16. Harmening DM, Walker PS. Alternative technologies and automation in routine blood banking testing. Chapter 15. In: Harmening DM, ed. Modern Blood Banking & Transfusion Practices, 5th ed. Philadelphia, PA: 2005:293–302.
17. Seth M, Jackson KV, Winzelberg S, et al. Comparison of gel column, card, and cartridge techniques for dog erythrocyte antigen 1.1 blood typing. Am J Vet Res 2012;73:213–219.
18. Euler CC, Lee JH, Kim HY, et al. Survey of two new (Kai 1 and Kai 2) and other blood groups in dogs of North America. J Vet Intern Med 2016;30:1642–1647.
19. Mehta CR, Patel NR. Exact logistic regression: Theory and examples. Stat Med 1995;14:2143–2160.
20. Polak K, Acierino MM, Raj K, et al. Dog erythrocyte antigen 1: Mode of inheritance and initial characterization. Vet Clin Pathol 2015;44:369–379.
21. Cohen C, Fuller JL. The inheritance of blood types in the dog. J Hered 1953;44:225–228.
22. Symons M, Bell K. Canine blood groups: Description of 20 specificities. Anim Genet 1992;23:509–515.
23. Riehl J, Okura M, Mignot E, et al. Inheritance of von Willebrand’s disease in a colony of Doberman Pinschers. Am J Vet Res 2000;61:115–120.
24. Stokol T, Parry B. Efficacy of fresh-frozen plasma and cryoprecipitate in dogs with von Willebrand’s disease or hemophilia A. J Vet Intern Med 1998;12:84–92.
25. Ching YN, Meyers KM, Brassard JA, et al. Effect of cryoprecipitate and plasma on plasma von Willebrand factor multimers and bleeding time in Doberman Pinschers with type-I von Willebrand’s disease. Am J Vet Res 1994;55:102–110.
26. Iazbik MC, O’Donnell M, Marin L, et al. Prevalence of dog erythrocyte antigens in retired racing Greyhounds. Vet Clin Pathol 2010;39:433–435.
27. Gibson G, Abrams-Ogg ACG. Canine transfusion medicine. In: Day MJ, Kohn B, eds. BSAVA Manual of Canine and Feline Haematology and Transfusion Medicine, 2nd ed. Gloucester: British Small Animal Veterinary Association; 2012:289–307.
28. Daniels GL, Fletcher A, Garratty G, et al. Blood group terminology: 2004: From the International Society of Blood Transfusion committee on terminology for red cell surface antigens. Vox Sang 2004;87:304–316.
29. Montgomery WM Jr, Nance SJ, Donnelly SF, et al. MAM: A “new” high-incidence antigen found on multiple cell lines. Transfusion 2000;40:1132–1139.
30. Lomas-Francis C, Vege S, Velliquette RW, et al. Expansion of the Kell blood group system: Two new high-prevalence antigens and two novel K0 (Kellnull) phenotypes. Transfusion 2013;53:2887–2891.

31. Jensen L, Scott EP, Marsh WL, et al. Anti-Jo(a): An antibody defining a high-frequency erythrocyte antigen. Transfusion 1972;12:322–324.

32. Wardrop KJ, Reine N, Birkenheuer A, et al. Canine and feline blood donor screening for infectious disease. J Vet Intern Med 2005;19:135–142.

33. Wardrop KJ, Birkenheuer A, Blais MC, et al. Update on canine and feline blood donor screening for blood-borne pathogens. J Vet Intern Med 2016;30:15–35.

34. Lapierre Y, Rigal D, Adam J, et al. The gel test: A new way to detect red cell antigen-antibody reactions. Transfusion 1990;30:109–113.

35. Andrews GA, Chavey PS, Smith JE. Production, characterization, and applications of a murine monoclonal antibody to dog erythrocyte antigen 1.1. J Am Vet Med Assoc 1992;201:1549–1552.